Surficial Geology of the Middle Gila River Area, North-Central Pinal County, Arizona

by

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Arizona Geological Survey
Open-File Report 93-3

March 1993

Arizona Geological Survey
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Prepared in cooperation with the U.S. Geological Survey COGEOMAP Program

Introduction

Most of southern and western Arizona is covered with unconsolidated basin sediments that are not mapped in detail. Although these sediments have diverse physical characteristics, origins, and ages, they are generally mapped as generic units (e.g., Qal). This lack of detailed mapping is not unique to Arizona; it is estimated that 80% of the United States is still unmapped at intermediate or detailed scales (Molnia, 1992:191). With recent developments in geologic dating techniques and improved understanding of weathering processes, there is now greater opportunity to distinguish and map unconsolidated sediments into genetic and temporal units. Recently, concerns in environmental geology have provided the impetus for surficial geologic mapping in Arizona (Demsey, 1989; Jackson, 1990; Field and Pearthree, 1991; Huckleberry, 1992a). These maps are of value to the scientific community because they provide insight into paleoenvironments and geomorphic history (Bull, 1991). More importantly, however, surficial geologic maps "...can be applied to land-use management, assessment, and utilization, conservation of natural resources, groundwater management, and environmental protection." (National Geological Mapping Act of 1992 (Section 2(b))). A recent example of the applied value of surficial geological mapping is the re-evaluation of flood hazards on alluvial fans (Pearthree, 1991).

This report presents the results of surficial geologic mapping along a segment of the middle Gila River (MGR) in north-central Pinal County (Figure 1). The region mapped is contained within the Florence, Florence Southeast, North Butte, and Grayback quadrangles (1:24,000), and part of the Teapot quadrangle (1:24,000). The study area represents an upstream extension of surficial geologic mapping of the eastern part of the Gila River Indian Community (GRIC) (Huckleberry 1992a). Surficial geologic mapping of the MGR area complements a historical study of flooding along the MGR (Huckleberry, in progress). Primary funding for the surficial geologic mapping has been provided by the COGEOMAP project, a joint geologic mapping effort by the Arizona Geological Survey and the U.S. Geological Survey. Additional funding for the MGR study has been provided by Geological Society of America, Sigma Xi, and Chevron. Gratitude is extended to the Pinal County Flood Control District for providing aerial photographs, and to Keith Layton who granted permission for excavation of a backhoe trench on his property.

Methods

Surficial geologic mapping of the study area involved four primary stages. The first stage was the use of aerial photography to distinguish geological surfaces. Relatively large scale (1:33:000) black and white aerial photography was used for areas located in the Florence and Florence Southeast quadrangles, whereas smaller scale (1:58,000) color infrared photography was used for the North Butte and Grayback quadrangles. Differences in surficial characteristics including color, degree of stream dissection, and drainage patterns were used to separate surfaces into different genetic and temporal categories (Bull, 1991; Christensen and Purcell, 1985). Boundaries were traced onto 1:24,000-scale orthophotos.

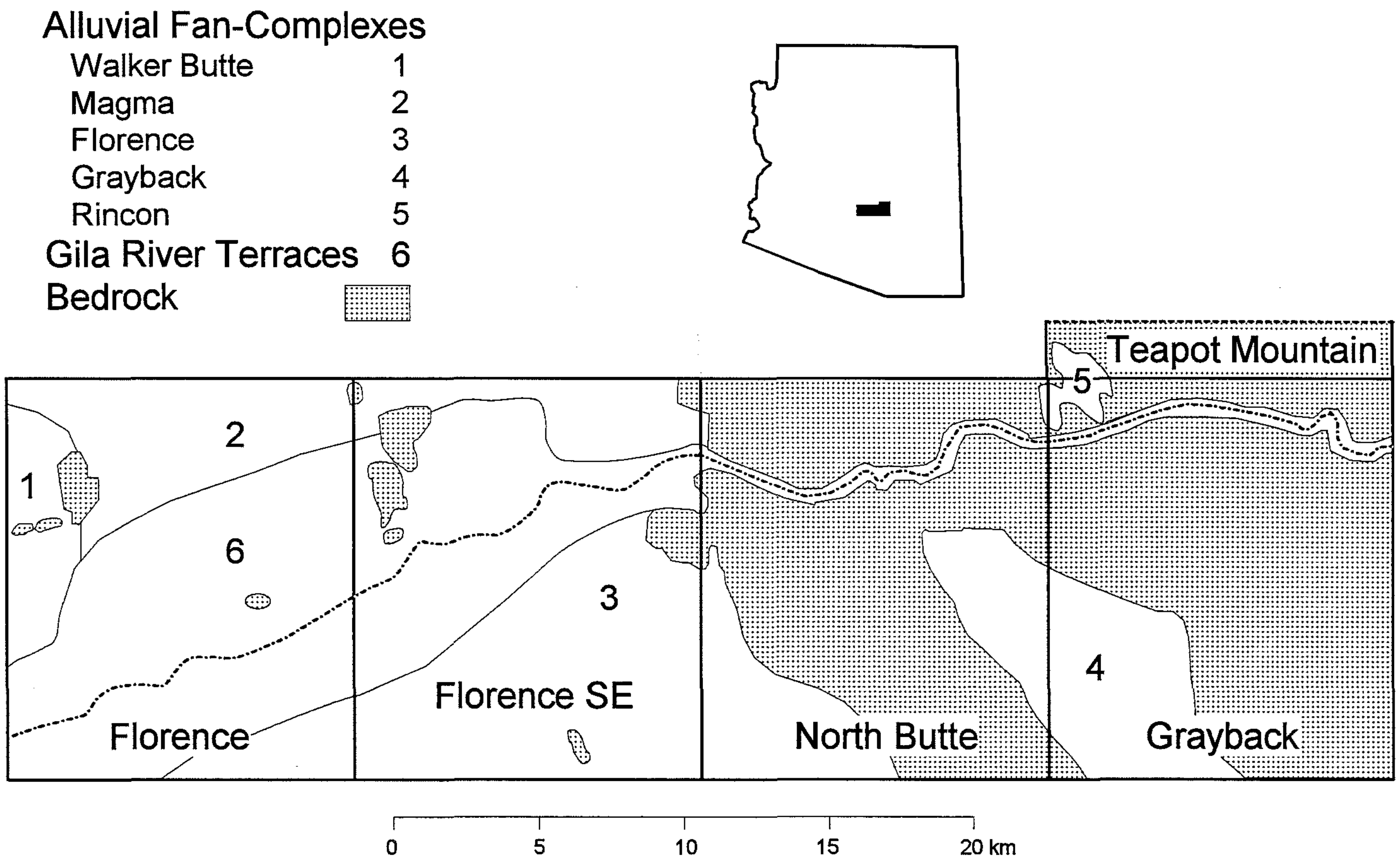

Figure 1. Location of study area and the general distribution of landforms.

The second stage involved field checking surfaces and analyzing weathering properties indicative of surface age. Soils were particularly useful for age-estimating and correlating surfaces (Birkeland, 1984; Morrison, 1967). Where natural soil exposures are absent, soil pits were excavated into surfaces interpreted to be stable and representative of the landform. Soils were described according to guidelines established by the Soil Survey Manual (Soil Survey Staff, 1951) and Guthrie and Witty (1981). Calcium carbonate development was characterized by the morphogenetic system of Gile and others (1966) and Machette (1985). Desert pavement and rock varnish development was also considered but found not to be as well preserved as in the eastern GRIC area.

The third stage was to check map-unit boundaries with soil surveys. A recent soil survey (Hall, 1991) covers part of the MGR valley located within the Florence and Florence Southeast quadrangles. In areas that have been cultivated, soil survey data were the primary criteria for distinguishing different surfaces.

The fourth and most difficult stage of surficial geologic mapping involved the correlation and age-estimation of surfaces. Correlating surficial deposits that vary in lithology, grain-size, and elevation can be problematic. Landforms with unique climatic/tectonic histories may have similar surficial properties. Likewise, surfaces that share similar histories may appear different. These problems of "equifinality" and "divergence" are the bane of earth scientists (Schumm, 1991) and admittedly limit the confidence of surface age-correlations in this study. In lieu of chronological control, topographic position and weathering characteristics were used to assign relative ages and correlate surfaces within the project area and the eastern GRIC area. Approximate ages were assigned to surfaces based primarily on comparison of soil formation to areas where soils are radiometrically dated (Bull 1991; Gile and others, 1981).

Geomorphic Setting

The study area is located within the Basin and Range physiographic province and includes both the Mexican Highland and Sonoran Desert subprovinces. The Grayback and North Butte quadrangles are located within the Mexican Highland subprovince, and the Florence and Florence Southeast quadrangles are located within the Sonoran Desert subprovince, and more specifically, the Phoenix Basin (Pewe, 1978). Mountains, pediments, stream terraces, and alluvial fans are common landforms in the MGR area. Areas in the Grayback and North Butte quadrangles are generally more stream-dissected and contain more bedrock surfaces than areas in the Florence and Florence Southeast quadrangles.

In describing geological surfaces in the MGR area, it is useful to divide the project area into two zones: Mountain Upland/Piedmont and River Valley/Basin Floor. The Mountain Upland/Piedmont zone includes steeply sloping bedrock surfaces, a pediment, and five alluvial fan-complexes. The pediment extends into the Grayback and North Butte quadrangles from the Tortilla Mountains located east of the project area. The fan-complexes are found throughout the project area and named after their source areas of sediment (Figure 1). The Walker Butte fan-complex includes sediments derived from a low series of granitic, rhyolitic, and schistose hills to the west of the Florence quadrangle. The Magma fan-complex is derived from largely schistose mountains north of the project area in the Mineral Mountain area. The Florence fan-complex is derived from granitic highlands extending between the Picacho and Tortilla Mountains to the south and southeast of the project area. The Grayback fan-complex is derived from the largely granitic Tortilla Mountains, whereas the Rincon fan-complex is a small group of alluvial fans derived from rhyolitic volcanics north of the project area in the Teapot quadrangle. Quaternary alluvial fan deposits within the North Butte and Grayback quadrangles overlie tilted Tertiary fanglomerates and pediment (Reynolds, 1988).

The River Valley/Basin Floor zone includes MGR stream terraces and poorly defined, low gradient surfaces that extend across basin floors. Within the Phoenix Basin, five MGR terraces are recognized including the Holocene flood plain, three spatially extensive terraces, and two small and isolated terraces. In the upstream, mountainous reach, there are three erosional stream terraces cut into bedrock. Lastly, there are small, isolated sand dunes north of the MGR in the Florence and Florence Southeast quadrangles.

Map Units

Three primary symbols are used to distinguish surfaces in the MGR area: Y (young), M (middle or intermediate), and O (old). A lower case "a" following one of these primary symbols denotes alluvial fan surfaces and channels. The subscript "p" indicates shallow, buried pediment where bedrock is commonly seen in stream channels. Primary symbols may be subdivided into secondary (e.g., M1 and M2) and tertiary (e.g., Ya1 and Ya2) levels. If a landform has characteristics transitional between two map units, then both are presented and separated by a slash (e.g., Y2/Y1). Sand dunes are denoted by "Ye". In addition to the Y-M-O system, MGR strath terraces, i.e., erosional terraces cut into bedrock in the North Butte and Grayback quadrangles are identified as Ms1, Ms2, and Ms3 in order of decreasing age. Other symbols include "b" for steeply sloping bedrock and 'Tsm" for middle Tertiary fanglomerates.

Where boundaries between temporally discrete surfaces are distinct, the boundary is marked by a solid line. Where surface characteristics change gradually, a dashed line is used to mark the approximate location of the boundary. Where a surface cannot be traced with certainty due to agricultural fields, a dotted line is used to demarcate agricultural field boundaries. This latter boundary may separate a detailed secondary or tertiary level unit designation with a less detailed, primary designation.

Mountain Upland/Piedmont Surfaces

Ya2

Modern ephemeral streams draining the piedmont areas are labeled Ya2. Relatively small Ya2 channels are lined with palo verde (*Cercidium*), mesquite (*Prosopsis*), and ironwood (*Olneya*). Larger channels including Box O[1], Donnelly, and Zelleweger washes also contain desert willow (*Chilopsis*) and tamarisk (*Tamarix*). Relatively unoxidized, interbedded sands, gravels, and cobbles comprise Ya2 alluvium. Drainage patterns range between distributary to anastomosing in these channels (see Table 1 for surface characteristics). Ya2 surfaces are modern and support periodic streamflow.

Ya1

Holocene alluvial surfaces that have incipient soil development are labeled Ya1 (Table 1). Commonly Ya1 surfaces are located at the distal ends of alluvial fans and occur as interfluves in areas of distributary drainage. Some Ya1 surfaces also occur as low terraces adjacent to Ya2 channels. Alluvial grain sizes range from very fine sand to cobbles. Ya1 soils contain cambic, weak calcic (Stage I or less), and Cox horizons (Birkeland, 1984; Soil Survey Staff, 1975:45; Appendix A). Soils classify as Torrifluvents, Camborthids, and Calciorthids (Soil Survey Staff, 1975:168, 170, 189).

Based primarily on soil development, Ya1 surfaces are age-estimated to be younger than 10 ka[2]. They correlate in age with Bull's (1991) Q4a and Q3c surfaces in the lower Colorado River Valley. The alluvium underlying the Ya1 surface correlates in age with the Fillmore alluvium along the middle Rio Grande River near Las Cruces (Gile and others, 1981).

Ma2

Late Pleistocene alluvial fan surfaces labeled Ma2 are common in bajada areas south and north of Florence (Table 1). Sediment sizes range from sand to cobbles. Compared to Ya1 surfaces, streams are more deeply incised into Ma2 surfaces, and soils on interfluves contain weakly developed argillic horizons (Soil Survey Staff, 1975:26) and calcic horizons with Stage I-II development (Appendix A). These soils classify as Camborthids, Calciorthids, and Haplargids (Soil Survey Staff, 1975:159). Desert pavement is variable ranging from moderately developed to absent.

Ma2 surfaces correlate in age with Bull's (1991) Q3a (8-12 ka) and some of the younger Q2c surfaces (12-70 ka). Ma2 surfaces also correlate in age with Gile and others' (1981) Isaac's Ranch surface which they age-estimate at 8-15 ka. A reasonable age estimate for Ma2 surfaces is 10-20 ka (Table 1).

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[1]Box O Wash is also known as Big Wash.

[2] 1 ky = 1,000 years; 1 ka = 1 ky before present; 1 My = 1,000,000 years; 1 Ma = 1 My before present (North American Commission on Stratigraphic Nomenclature, 1983)

Table 1. Physical Characteristics and Age Estimates of Geologic Surfaces.

Mountain Upland/Piedmont

Surface	Dissection	Drainage	Soil Horizons	CO3 Stage	Pavement/Varnish	Terrace Name	Soil Profile	Surface Age Estimate
Ya2	-	distrib.-anast.	C	-	none	-	-	modern
Ya1	> 1 m	distrib.-dend.	Bw, Bk, Cox	I	none	-	17	< 10 ka
Ma2	< 3 m	dendritic	Bk, Bt, Cox	I - II+	none to moderate	-	19	10-20 ka
Ma1	> 3 m	dendritic	Bt, Bk, Bkm	II - IV	moderate	-	16	100-500 ka
Oa	> 6 m	dendritic	Bkm	III - V	none to weak	-	18	0.5-1.0 Ma

River Valley/Basin Floor

Surface	Dissection	Drainage	Soil Horizons	CO3 Stage	Pavement/Varnish	Terrace Name	Soil Profile	Surface Age Estimate
Y2	-	distrib. - anast.	C	-	none	-	-	modern
Y2/Y1	< 2 m	distrib. - dend.	C	-	none	-	-	< 1 ka
Ye	-	-	A,C	I	none	-	21	< 4 ka
Y1	< 2 m	distrib. - dend.	Bw, Bk, Cox	I	none	Adamsville	14	< 8 ka
M3	< 2 m	dendritic	Bk	I - II+	none-weak	Stiles	9, 22	6-12 ka
M2	2 - 3 m	dendritic	Bk	II - III	none-moderate	Bogart	12	10-40 ka
M1	> 4 m	dendritic	Bt, Bk, Bkm	IV	weak-moderate	Florence	10,15	0.2-1.0 Ma
M1'	2 - 3 m	dendritic	Bt, Bk, Bkm	II - III	none-moderate	-	13,20,21,23	< 1.0 Ma
M	< 4 m	dendritic	Bt, Btn, Bk	II - III	none	-	-	20-200 ka
O	> 8 m	dendritic	Bkm, Bkqm	III - IV+	weak-strong	Target	11	1.0-2.0 Ma

Strath Terraces

Surface	Dissection	Drainage	Soil Horizons	CO3 Stage	Pavement/Varnish	Terrace Name	Soil Profile	Surface Age Estimate
Ms3	2 - 4 m	dendritic	Bk, Bkm	III	weak-moderate	-	26	100-200 ka
Ms2	6 - 10 m	dendritic	Bt, Bkm	III - IV	weak-moderate	-	24	200-500 ka
Ms1	> 10 m	dendritic	Bkqm	IV+	none- weak	-	25	0.5-1.0 Ma

Ma1

Geologic surfaces developed on middle to late Pleistocene alluvial fan sediments are labeled Ma1 (Table 1). Ma1 surfaces dominate the Florence, Magma, and Grayback fan complexes. Alluvial grain sizes generally range from sand to cobbles. Along Donnelly Wash (North Butte quadrangle), there are exposures of Ma1 sediments that show Ma1 fan sediments overlying bedrock and tilted Tertiary fanglomerates. Ma1 surfaces are heavily dissected and contain mature soils with argillic, calcic, and petrocalcic (Stage II-III+) horizons (Appendix A). These soils classify as Calciorthids, Paleorthids, Haplargids, and Paleargids (Soil Survey Staff, 1975:165, 176). Desert pavements are weakly developed.

Ma1 surface characteristics are like those of Bull's (1991) Q2a surface (400-730 ka) and Gile and others' (1981) Jornada I surface (250-400 ka). The Ma1 surface is age-estimated at 100-500 ka (Table 1).

Oa

The oldest alluvial fan surfaces in the MGR area are labeled Oa (Table 1). Oa surfaces are located in the Magma and Florence fan-complexes (Figure 1). These alluvial fan deposits have been deeply dissected into a series of ridges. Alluvial grain sizes range from sand to boulders. Soil development is advanced and characterized by argillic horizons and Stage III-IV carbonates (Appendix A); these soils classify as Paleorthids and Paleargids. Oa surfaces generally lack desert pavement and rock varnish development, and the presence of petrocalcic fragments at the surface indicates erosion of the original surface.

If Oa surfaces are erosional, then they do not represent the age of the original landform. Nonetheless, soil morphology indicates that the more stable parts of these surfaces are older than any of the other fan surfaces in the area. Oa surfaces correlate in age to the Q1 surface in the lower Colorado River Valley (Bull, 1991) and the Dona Ana surface of the middle Rio Grande Valley (Gile and others, 1981). Both of these surfaces have open-ended age estimates (> 1.2 Ma for Q1 and > 400 ka for Dona Ana). A reasonable age estimate for the Oa surface is 0.5-1.0 Ma (Table 1). The underlying deposits are undoubtedly much older, possibly as old as Pliocene (5.3-1.6 Ma).

River Valley/Basin Floor

Y2

The modern MGR channel is labeled Y2 (Table 1). Above the Hayden-Ashurst Diversion Dam, MGR streamflow is perennial but regulated by Coolidge Dam. Below the Hayden-Ashurst Diversion Dam, the MGR channel is dry except during periods of above average precipitation when excess water is released from Coolidge Dam, or when floods are generated by the San Pedro River system. The Y2 channel contains a smaller, low flow channel that has been formed by periodic streamflow. This low flow channel has a width/depth ratio greater than 20, which is common for mixed load and bedload streams

(Schumm, 1977). Further downstream, the width/depth ratio of the low flow channel decreases reflecting a smaller mean particle size of the streamload and the effects of encroaching, bank-stabilizing vegetation such as tamarisk (Haschenberger, 1988; Huckleberry, 1992a). The MGR channel has a history of dramatic changes in planimetric form with the greatest change occurring in 1905 when the channel transformed from relatively narrow and sinuous to wide and braided (Huckleberry 1992b). Similar channel changes have been noted for the upper Gila river in the Safford Valley (Burkham, 1972). These channel dynamics are probably related to changes in flood frequency and magnitude due to secular climatic variability. Sediments within the Ya2 channel are modern to historical in age.

Ye

On the north side of the MGR in the Florence and Florence Southeast quadrangles are three small areas (< 6 hectares) of eolian sand that are labeled Ye (Table 1). The sands are well sorted, probably derived from the flood plain of the MGR, and are situated on top of denuded Pleistocene stream terraces. At present the dunes are relatively stable as evidenced by the presence of creosote (*Larrea*), cholla (*Opuntia*) and various grasses at the surface. However, archaeological artifacts at the surface represent a deflated lag and suggest some surface erosion. Overall surface instability is further supported by minimal pedogenesis (Appendix A). Soils classify as Torripsamments (Soil Survey Staff, 1975:204).

Ye sand dunes are at least 1 ky old as indicated by the presence of Hohokam pottery sherds and lithic artifact clusters, the latter possibly being Archaic (i.e., pre-Hohokam). Ye sediments are probably < 4 ka (Table 1).

Y2/Y1

On both sides of the Y2 channel are discontinuous, low stream terraces that are inundated during infrequent floods (e.g., 50-year or greater events[3]). These terraces are labeled Y2/Y1 and represent a transitional surface between the MGR and the main Holocene terrace. Y2/Y1 terraces contain both channel (crudely bedded coarse sands, gravels, and cobbles) and overbank (finely laminated clays, silts, and fine sands) sediments. Soil development is limited to slight humification at the surface and some bioturbation; soils classify as Torrifluvents. These sediments are less than 1 ka (Table 1).

Y1 (Adamsville Terrace)

The youngest continuous terrace along the MGR is labeled Y1 (Table 1) and informally named the Adamsville Terrace after the town of the same name that was destroyed by MGR floods during the late 19th century (Barnes, 1988:10). Historically, the Adamsville Terrace contained extensive riparian plant communities with cottonwood (*Populus*), willow (*Salix*), and mesquite (*Prosopsis*). Most of these plant communities were destroyed by clearing for agriculture, woodcutting, and lowered water tables (Rea, 1983). Today the Adamsville terrace is largely covered by a mosaic of agricultural fields. The Adamsville terrace contains both channel and overbank deposits with the latter

[3] Y2/Y1 surfaces were flooded during the October, 1983 and January, 1993 floods.

dominating the upper 2 m of the terrace. Alluvial bedforms near the surface are absent to weakly expressed due to bioturbation. Other examples of pedogenesis include humification and oxidation (Appendix A). Oxidized Y1 sediments occur at depth and are described as cambic (Bw) horizons (Hall, 1991), but are probably better defined as Cox horizons (Birkeland, 1984:8). In places, there is evidence of incipient calcification including small (< 1 cm) rhizoliths of $CaCO_3$ at 1.0 m depth. Soils on the Adamsville Terrace classify as Torrifluvents and Camborthids (Hall, 1991).

The Adamsville Terrace is age estimated at < 8 ka (Table 1). Two samples of detrital charcoal collected from within 2 m of the surface of the Adamsville Terrace near Casa Grande National Monument have radiocarbon ages of 4,730 $\pm$65 years before present (AA-8376) and 695$\pm$55 years before present (AA-8377)[4] (Huckleberry, in progress). These radiocarbon age estimates are congruent with the weakly developed soils. The Adamsville Terrace correlates to the Lehi Terrace on the Salt River in the Mesa-Tempe area (Pewe, 1978) and to the Q3b and Q3c surfaces in the lower Colorado River Valley (Bull, 1991). Y1 alluvium correlates in age with Fillmore deposits located along the middle Rio Grande River that have been radiocarbon dated at 1.0-7.5 ka (Gile and others, 1981). Older, Pleistocene alluvium lies beneath Y1 alluvium as evidenced by a relatively intact *Probicidean* tusk retrieved 7.0-9.0 m beneath the Y1 surface in a gravel quarry near Sacaton (Huckleberry, 1992a).

M3 (Stiles Terrace)

The M3 surface is a small (< 1 km^2), isolated MGR terrace located on the north side of the river north of Florence (Figure 2; Table 1). It is herein named the Stiles Terrace after Bill Stiles, an early settler who was killed in this vicinity. Unlike the major terraces along the MGR which are aggradational, the Stiles Terrace is an erosional terrace (see MGR Terraces below). It formed by the MGR cutting laterally into an older (M1) terrace. The Stiles Terrace tread is not planar; areas where MGR cobbles extend to or near the surface tend to be highest. These elevated areas are believed to be more resistant remnants of the older terrace. In these elevated, cobbly areas, there is weak rock varnish and desert pavement development. In the lower areas, soils are silty and subject to deflation. Soils on the elevated remnants and in cobbly deposits at depth tend to have Stage II calcium carbonate development (Appendix A). Most of the terrace, however, contains weakly developed, calcic (Stage I) soils. In places, these soils are buried by tributary alluvium (Figure 2). The more developed Stiles Terrace soils are believed to be truncated soils from the older terrace that have been slightly modified by Holocene pedogenesis. Soils on the Stiles Terrace classify as Torrifluvents and Calciorthids (Appendix A) .

The Stiles Terrace was formed during the early Holocene. It has no counterparts on the Salt River, although based on soil formation, this terrace is comparable in age to the Blue Point Terrace (Pewe, 1978). The Stiles Terrace also has no counterparts on the

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[4] Radiocarbon dates were analyzed at the National Science Foundation's Accelerator Mass Spectrometry Laboratory at the University of Arizona.

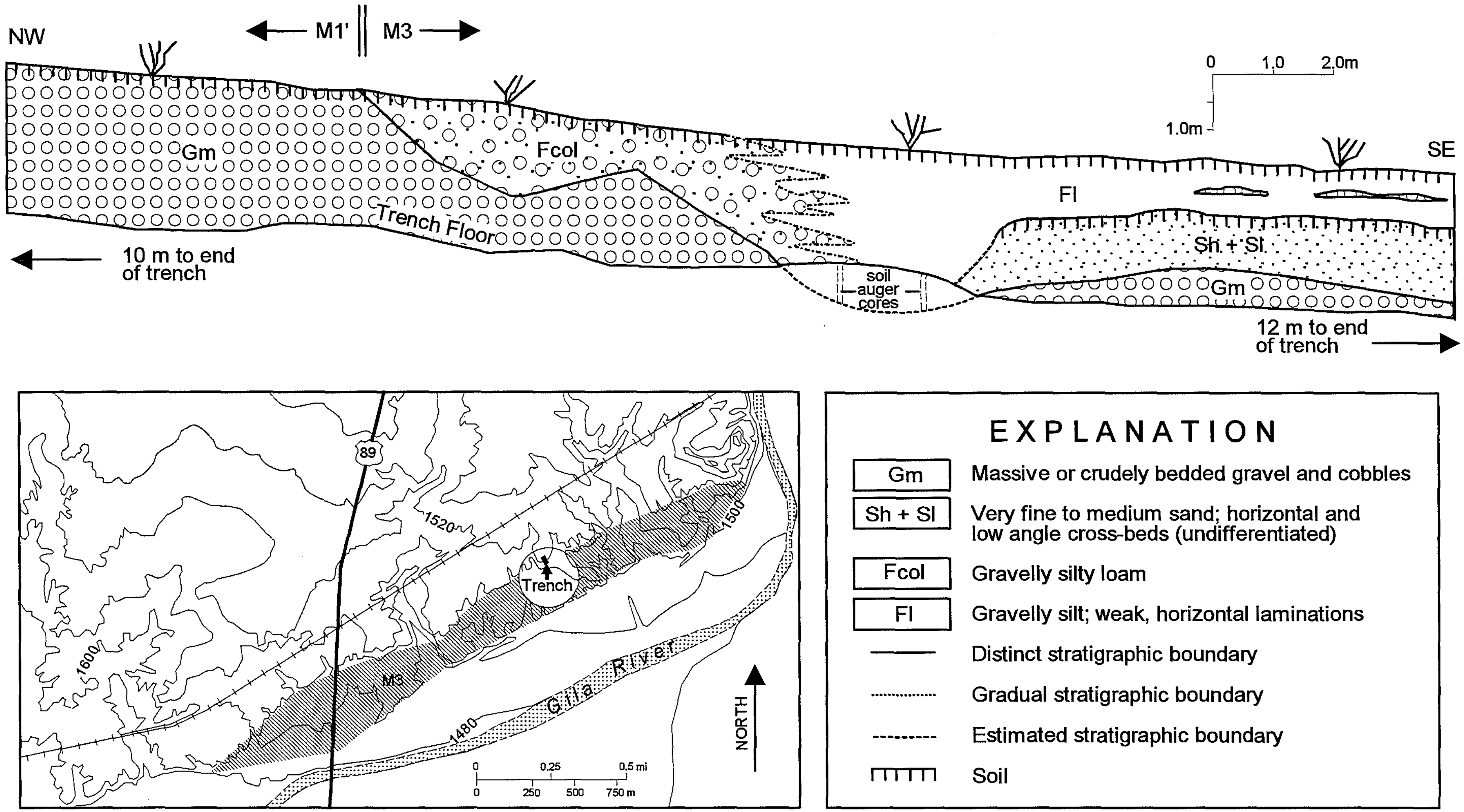

Figure 2. Stiles Terrace (M3) topography and stratigraphic profile of Florence-Stiles Terrace interface (SW1/4, SE1/4, NW1/4, SW1/4, Sec. 19, T.4 S., R. 10 E.).

Colorado and Rio Grande rivers. A reasonable age-estimate for the Stiles Terrace is 6-12 ka (Table 1).

M2 (Bogart Terrace)

The M2 surface is located approximately 6 km west of Florence on the south side of the MGR and is herein named the Bogart Terrace after Bogart Wash, a local drainage that transects the terrace. Like the Stiles Terrace, the Bogart Terrace is isolated, small in area (< 2 km^2), and probably formed by MGR lateral erosion into an older (M1) terrace. Although at similar heights above the MGR, the Bogart Terrace appears to be older than the Stiles Terrace. The Bogart Terrace is more dissected by tributary streams and contains more oxidized soils with hues ranging 5-7.5YR (Appendix A). This oxidation may be misleading, however, since it appears that some of the pedogenic properties are inherited from the older terrace (see Soil-Landform Relationships below). Bogart Terrace soils classify as Calciorthids.

Because the Bogart Terrace is interpreted to be an erosional terrace, it is not correlated to any of the terraces on the Salt, Colorado, and Rio Grande rivers. The Bogart Terrace is age estimated at 10-40 ka (Table 1).

M1 (Florence Terrace)

The M1 surface is informally named the Florence Terrace after the town of Florence (Table 1). Although variably preserved, the Florence Terrace is found on both sides of the MGR and represents a major depositional landform. M1 alluvium is composed of sand, gravel, and cobble channel deposits with interfingered silty and clayey overbank sediments. Desert pavement and rock varnish development is only weak to moderate, but significant surface antiquity is suggested by pitted weathering of granitic clasts at the surface. The Florence Terrace contains both surface and buried soils. Surface soils are strongly developed with calcic and petrocalcic horizons (Stage III-IV; Appendix A) and classify as Calciorthids and Paleorthids. Buried soils are well developed with argillic and petrocalcic horizons and classify as Paleargids.

The Florence Terrace is middle to late Pleistocene in age and the MGR equivalent to the Salt River's Mesa Terrace (Pewe, 1978). M1 sediments correlate in age with Q2a alluvium along the lower Colorado River (Bull, 1991) and Jornada I alluvium in the Las Cruces area (Gile and others, 1981). Buried soils (see MGR-10 and MGR-15, Appendix A) indicate that formation of the Florence Terrace was episodic. The buried soil at MGR-10 represents a depositional hiatus of at least 100 ky years. Following formation of this soil, the MGR aggraded, then downcut again, allowing for formation of the surface soil. A reasonable age estimate for the Florence Terrace is 0.2-1.0 Ma (Table 1).

M1' (degraded Florence Terrace)

It is rare for the Florence Terrace to have a well preserved, planar morphology. In most places, this terrace has been heavily eroded such that the original tread is missing. This denuded surface is designated M1' to denote a degraded Florence Terrace (Table 1).

The M1' surface is comprised of a series of low, rounded interfluves and moderately incised stream channels. Desert pavement and rock varnish development is quite variable ranging from absent to moderate development. Fragments of petrocalcic horizons and $CaCO_3$ nodules are common at the surface and represent an erosional lag. Soil development also varies tremendously on the M1' surface reflecting diachronous erosion of the Florence Terrace. Older soils are calcareous with Stage III $CaCO_3$ development; younger soils are calcareous with Stage I-II $CaCO_3$ development. M1' soils generally classify as Calciorthids (Appendix A).

M1' surfaces vary in age depending on the time of erosion. They are equal or younger in age than M1 surfaces. A wide age range of < 1.0 Ma is assigned to the M1' surface (Table 1).

M

In the southwestern part of the Florence quadrangle the MGR terraces converge into a relatively nondescript, Pleistocene surface referred to as M. This surface grades into the main valley floor of the Picacho Basin and the single Pleistocene MGR terrace located in the GRIC (Huckleberry, 1992a). Low gradient surfaces in the northwestern part of the Florence quadrangle that slope towards Magma Wash and Queen Creek are also mapped as M. M surfaces are cultivated and thus difficult to analyze. Descriptions of M surface characteristics presented in Table 1 are based on descriptions from the eastern part of the GRIC. The most recent soil survey of the area (Hall, 1991) indicates that soils on the M surface include Calciorthids, Haplargids, and Natrargids (Soil Survey Staff, 1975:163). Such soils are indicative of late Pleistocene surfaces. A reasonable age-estimate for the M surface is 20-200 ka.

O (Target Terrace)

The O surface is informally named the Target Terrace after the Arizona National Guard's Target Range north of the MGR where the terrace is best preserved (Table 1). Having been exposed to erosion for most of the Quaternary, the Target Terrace seldom retains its original terrace form and instead appears as a series of hills and isolated ridges. Streams draining the Target Terrace on the north side of the MGR have a high drainage density and viewed from the air form a distinct dendritic drainage pattern reminiscent of fine-textured badlands. There are few stratigraphic exposures of O deposits; shallow (< 2 m) exposures reveal predominantly channel deposits with clasts ranging in size from gravels to boulders. Coarse-grained clasts at the surface are highly pitted, and fine-grained rocks are commonly fractured. Most of the Target Terrace surface is sloping, and there is no desert pavement development. However, in a few places, surfaces are relatively level, and desert pavement and rock varnish are moderately to strongly developed. Also at the surface are fragments of petrocalcic horizons indicating previous erosion. Target Terrace soils have thick petrocalcic horizons with Stage IV+ morphology. Secondary silica incorporated within the petrocalcic horizons appears as light brown, thin laminae. These soils classify as Durorthids (Hall, 1991; Soil Survey Staff, 1975:174).

The Target Terrace correlates in age with the Salt River's Sawik Terrace (Pewe, 1978), Bull's (1991) Q1 surface, and Gile and others' (1981) La Mesa surface. The Target Terrace is estimated to be 1.0-2.0 My old (Table 1).

Ms3

A strath terrace discontinuously preserved 5-15 m above the MGR within the North Butte and Grayback quadrangles is herein named Ms3 (Table 1). This terrace is cut into bedrock and contains a veneer of alluvium that is generally less than 3 m thick. The Ms3 surface is dissected but relatively level suggesting that recent denudation has been limited to the larger stream courses (i.e., vertical incision has predominated over lateral erosion). Although the Ms3 surface is close to the modern MGR, soils contain Stage II to IV $CaCO_3$ development (Appendix A) indicating considerable soil antiquity. The degree of calcification, however, is noticeably less than on the higher strath terraces. Ms3 soils classify as Calciorthids and Paleorthids.

Because strath and aggradational terraces are formed by different processes, the MGR strath terraces are not correlated to the aggradational terraces in the Florence area or along the Salt, Colorado, and Rio Grande rivers. Based on soil formation, the age of the Ms3 surface is probably 100-200 ka (Table 1).

Ms2

The Ms2 surface is the intermediate MGR strath terrace situated 25-30 m above the modern river (Table 1). This surface is discontinuous and generally preserved in small patches less than 160 hectares in area. Compared to the Ms3 surface, the Ms2 surface is more dissected, and the interfluves are more rounded. Soils are well developed with red, argillic horizons and Stage III-IV petrocalcic horizons; these soils classify as Paleargids (Appendix A). Based on soil formation, the estimated age of the Ms2 surface is 200-500 ka (Table 1).

Ms1

The highest and oldest strath terrace is named Ms1 and lies 40-65 m above the MGR (Table 1). Ms1 is highly eroded and preserved in only two places: 1) north-northeast of Grayback Mountain on the south side of the MGR and 2) southwest of North Butte on the north side of the MGR. Tributary streams are incised over 10 m into the Ms1 surface, and the interfluves are rounded. Ms1 soils consist of a truncated petrocalcic horizon buried by loess (Appendix A). The petrocalcic horizon contains Stage IV+ development and light brown laminae of secondary silica. Broken blocks of this horizon are common at the surface indicating surface erosion and bioturbation. These soils classify as Durorthids and probably require at least 500 ky to develop. Because Ms1 is topographically lower than the early Pleistocene Target Terrace, it is estimated to be younger. The Ms1 surface is age estimated at 0.5-1.0 Ma (Table 1).

Middle Gila River Terraces

From a geomorphological perspective, the most interesting aspect of the project area is the flight of downstream-converging MGR terraces in the Florence area (Morrison, 1985; Pewe, 1978; Figure 3). Within the Florence and Florence Southeast quadrangles, there are three major terraces: Adamsville (Y1), Florence (M1) and Target (O). The Stiles (M3) and Bogart (M2) terraces and the Y1/Y2 surface represent minor, discontinuous MGR terraces. Also of interest and not previously studied are the three strath terraces (Ms3, Ms2, and Ms1) located in the Grayback and North Butte quadrangles. Other terraces in the Gila River system have been identified upstream and downstream from the project area (Table 2). The number and type of terraces and their height above the modern channel vary throughout the system. This implies that different reaches of the Gila River system have responded to local controls in terrace formation. Knowing how and why these stream terraces formed is important because these landforms provide insight into the climatic and tectonic history of the region. This section discusses in greater detail the nature and origin of the MGR Terraces.

Table 2. Terraces Identified along the Gila River and Its Tributaries.

Location	Number of Terraces above Holocene flood plain	Height (m) above Holocene flood plain	References
Duncan Valley	5	6-104	Morrison (1965)
San Carlos River Valley	6	9-120	Anderson (1990)
Grayback-North Butte	3	5-65	Huckleberry (this report)
Florence Area	4	2-74	Huckleberry (this report)
Eastern Gila River Indian Community Area	1	3-6	Huckleberry (1992a)
Mesa Area (Salt River)	3	3-72	Pewe (1978)
Gillespie Dam	3	6-24	Lee and Bell (1975)
Gila Bend to Yuma	1	20-36	Bryan (1925) Morrison (1985)

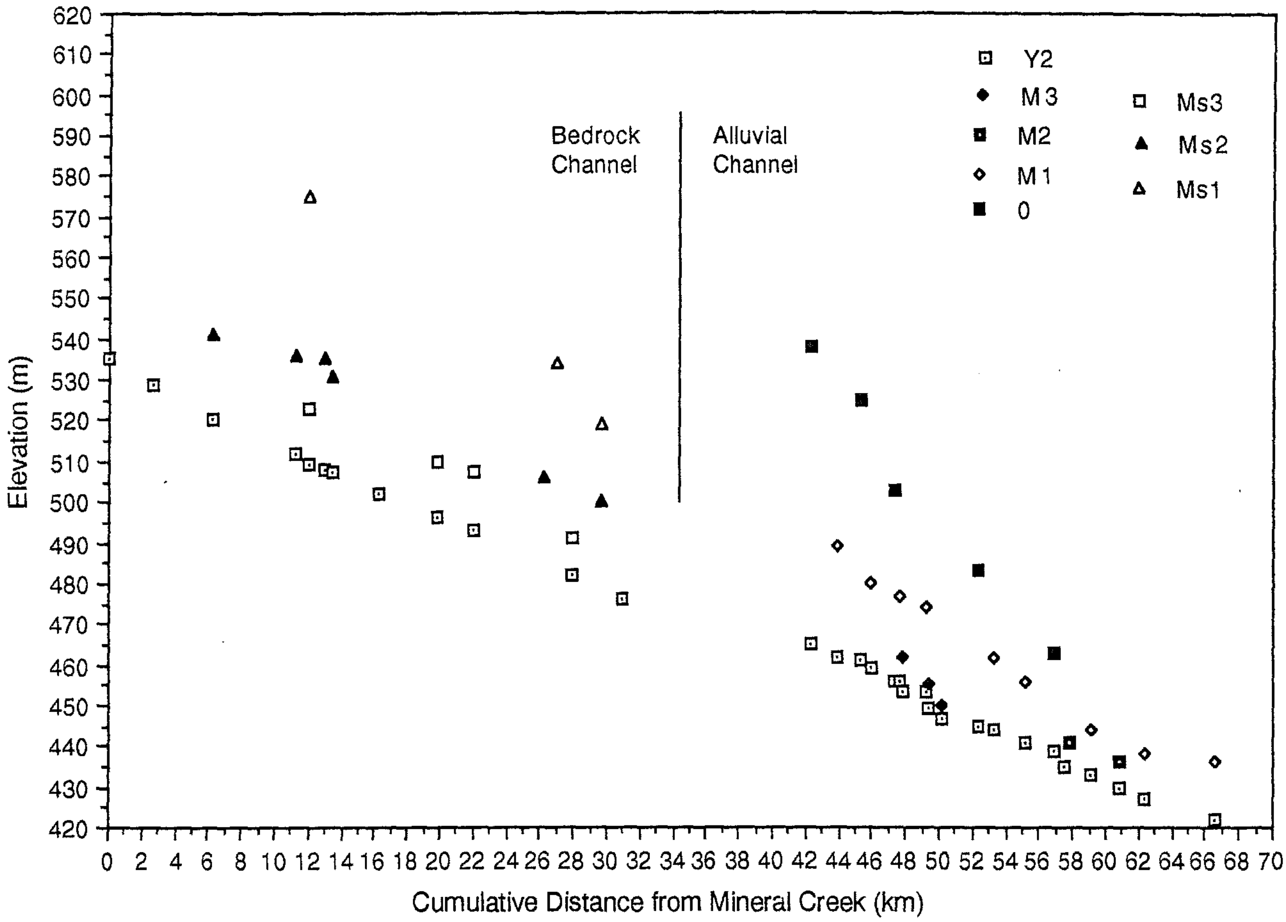

Figure 3. Longitudinal profiles for Middle Gila River terraces between Mineral Creek and the Southern Pacific Railroad Bridge.

MGR Terraces Near Florence

Stream terraces are defined by their formational processes. **Aggradational** terraces form by aggradation and subsequent incision and tend to be composed of thick channel and overbank deposits (Bull, 1990; Leopold and Miller, 1954; Ritter, 1986:267). The Adamsville, Florence, and Target terraces are aggradational terraces. MGR incision into the Adamsville Terrace is slight and recent, and this terrace also represents the modern flood plain of the MGR. The channel deposits in these terraces consist of poorly bedded but imbricated cobbles and gravels with some lenses of cross-bedded coarse to medium sands. Overbank deposits consist of horizontally bedded silts and fine sands and organic clays and are more common in the Adamsville Terrace than in the older terraces. This may reflect better preservation in the younger terrace or a change in the flow regime of the MGR during the Holocene.

Aggradational terrace formation can be contemporaneous within a given reach, or it can be time transgressive (Bull, 1991:213). Whether one interprets terraces as isochronous or diachronous depends on the timeframe being considered and the resolution of age-estimating the terraces (see Schumm, 1991). If aggradation during the formation of a terrace varies spatially at time scales of 10^2-10^3 years, and the resolution of age estimates for the terraces is at time scales of 10^3-10^4 years, then it is not possible to recognize noncontemporaneity. This situation applies to the MGR terraces where resolution of the age estimates for the Target and Florence terraces is at time scales of 10^4-10^5 years. Without resolute Quaternary dating techniques, it is difficult to address the spatial-temporal dimensions of Pleistocene terrace formation. It is possible to address the contemporaneity of Holocene surfaces like the Adamsville Terrace through the use of radiocarbon dating. However, at present, there are insufficient radiocarbon dates from the Adamsville Terrace to define spatial variability in surface age.

Another type of stream terrace is formed by erosion into a preexisting aggradational terrace. This type of terrace is often referred to as a **fill-cut** terrace (Leopold and Miller, 1954). The Stiles and Bogart terraces are interpreted as fill-cut terraces. The evidence for this interpretation is both topographic and stratigraphic. Both the Stiles and Bogart terraces have uneven treads. The topography of the Stiles Terrace, however, is particularly interesting in that cobbly interfluves extend from the degraded Florence Terrace (M1') onto the eastern portion of the Stiles Terrace (Figure 2). This suggests that channel deposits of the Florence Terrace are continuous with the Stiles Terrace. In an effort to confirm stratigraphic continuity, a backhoe trench was excavated perpendicularly across the scarp separating the Florence and Stiles terraces (Figure 2). Florence Terrace channel deposits (Gm) consisting of massive and poorly imbricated cobbles and gravels extend below the floor of the trench but reemerge on the Stiles Terrace. A soil auger was used to trace the channel deposits below the floor of the trench. On the Stiles Terrace, the channel deposits are overlain by MGR horizontal and low angle trough cross-bedded sands (Sh and Sl) typical of scour fills (Miall, 1978). A weakly developed, calcareous paleosol is developed into these sands (see Soil MGR-23 in Appendix A). The paleosol is buried by poorly bedded silts and fine sands (Fl) with occasional lenses of gravels; these upper sediments are interpreted as tributary alluvium derived from the degraded Florence Terrace. At the interface between the two terraces is a wedge of colluvium (Fcol) that interfingers with the tributary alluvium. A former tributary channel truncates the buried paleosol at this interface. The trench was not deep enough to prove the channel deposits in the Florence and Stiles terraces are part of the same stratigraphic unit, but stratigraphic continuity is supported by the comparable size and bedding of the Gm deposits as well as similar calcium carbonate development (thin discontinuous rinds on the bottom sides of clasts).

The Bogart Terrace is similar to the Stiles Terrace in that it is small, isolated, and situated between the Adamsville and Florence terraces. The alluvial stratigraphy of the Bogart Terrace was not exposed, but soil evidence suggests that this terrace is also an erosional, fill-cut terrace. Soils on the Bogart Terrace contain a Bk horizon that is red (5YR) and cemented by a noncalcareous precipitate (see Soil MGR-12 in Appendix A). Given the red colors, it was believed that some type of iron oxyhydroxides was a likely candidate for the cement. However, x-ray diffraction analysis[5] of the < 2 micrometer fraction revealed only a trace of goethite (Figure 4); most of the fine fraction is dominated by primary minerals like quartz and orthoclase. Morphologically similar Bk horizons are common at depth in soils on the degraded Florence Terrace. X-ray diffraction analysis of the fine fraction from one of these horizons, the 2Bk horizon in Soil MGR-20 (Appendix A), revealed mostly primary minerals and no iron oxyhydroxides (Figure 4). This suggests that 1) these soils are not greatly modified by pedogenesis, and 2) they are of similar age. A viable hypothesis is that both soils are B or Cox horizons of an older Pleistocene soil within the Florence Terrace that were exhumed by the MGR.

If the Adamsville, Florence, and Target terraces are aggradational terraces, and the Stiles and Bogart terraces are fill-cut terraces, what mechanisms are responsible for their formation? Terrace formation may be driven by external forces, e.g., climate change and tectonism, or be the result of internal adjustments within the fluvial system, e.g., complex response terraces (Schumm, 1973). The major terraces near Florence are aggradational and were formed by MGR incision following an extended period of deposition. This shift was caused by changes in MGR discharge and sediment load or a tectonic change in the local base level of erosion.

Major climate changes associated with glacial-interglacial cycles during the Pleistocene can alter the discharge-sediment load relationships of rivers resulting in shifts from aggradation to degradation or visa versa. The direction of the climate change, i.e., glacial-to-interglacial or interglacial-to-glacial, responsible for a shift from aggradation to degradation is uncertain and will vary regionally depending on watershed characteristics and the nature of Pleistocene climate change. In addition, one type of climate change may result in both aggradation and degradation at different locations

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[5] X-ray diffraction analysis was performed using a copper target on a Siemens D-500 at the Department of Geosciences, University of Arizona.

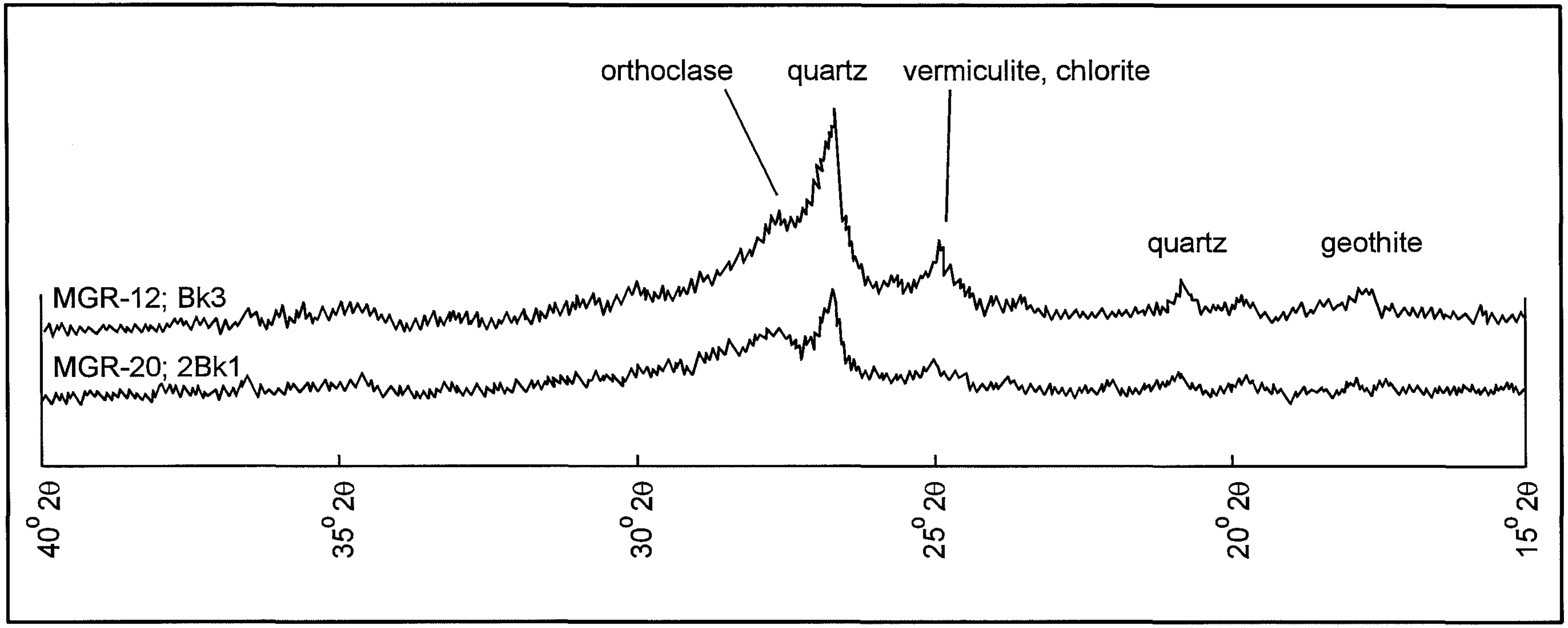

Figure 4. X-ray diffractograms of soil samples from horizon Bk3 in soil MGR-12 and horizon 2Bk1 in soil MGR-20

within a drainage system (Schumm, 1977). In the MGR area, the last major glacial to interglacial climate change, approximately 12 ka, coincides with MGR incision into the Stiles Terrace and possibly the Bogart Terrace. This suggests that a glacial-to-interglacial climate change is responsible for the formation of MGR aggradational terraces. Small terraces like the Stiles and Bogart terraces may be the result of internal adjustments within the MGR system.

If glacial to interglacial climate change drives MGR terrace formation, then it is puzzling that there are only three major terraces to record the 10 or more major glacial-interglacial cycles during the Quaternary (Bradley, 1985). If the MGR is sensitive to climate change, there should be more terraces. It may be that other terraces were created during the Quaternary, but these have been eroded or buried. Soil-geomorphic analysis suggests that it is probable that erosion removed some Pleistocene surfaces in the area (see Soil-Landform Relationships below).

Lastly, in discussing the origins of the MGR terraces near Florence, the relevance of the downstream-converging longitudinal profiles needs to be addressed. Pewe (1978) recognized this phenomenon on several major streams in the Phoenix Basin and suggested that it records some type of Quaternary tectonism. Since this pattern is seen on the margins of the Phoenix Basin only, and the gradients converge downstream, the implication is that the Phoenix Basin has been lowered relative to the Central Transition zone and Mexican Highlands physiographic subprovince. Converging aggradational terraces need not, however, be formed solely by tectonism; such terraces located along arid and semiarid streams have been attributed to climate change as well (Bull, 1991:208). Furthermore, a paucity of neotectonic features in the Phoenix Basin indicates that this area has not been witness to major faulting in the last 2 My (Menges and Pearthree, 1989). However, there may be a type of Quaternary tectonism occurring here that is not being manifested through the reactivation of high angle, normal, basin-bounding faults. It is probable that if the study area is experiencing crustal displacement, it is more of a tilting motion with the Phoenix Basin being tilted toward the west and southwest. Menges and Pearthree (1989) note that a zone of limited neotectonic faulting in Arizona is aligned northwest-southeast near the margins of the Colorado Plateau. This zone is also a region of elevated topography and maximum dissection suggesting possible Pliocene-Quaternary uplift. Such uplift may be the result of isostatic rebound created by late Cenozoic denudational unloading within the upper Gila River watershed (Shafiqullah and others, 1978). The effect of this uplift on the northern and eastern margins of the Phoenix Basin might be a west-southwestward tilting away from the Central Transition zone and Mexican Highlands subprovince. Thus Quaternary uplift remains a plausible hypothesis for the converging longitudinal profiles of the MGR and other Phoenix Basin river terraces.

Strath Terraces

Compared to the major aggradational terraces near Florence, the MGR strath terraces, Ms1, Ms2, and Ms3, are smaller, more discontinuous, and generally unpaired.

Ms1 and Ms2 are considerably dissected and eroded by tributary streams. In general, these terraces are characterized by a veneer of gravelly and cobbly alluvium over granite and some rhyolite. Unlike aggradational terraces, strath terraces are the product of prolonged fluvial stability whereby a river neither downcuts or aggrades but rather maintains a given level and cuts laterally (Bull, 1990). Such rivers are said to be in equilibrium, i.e., discharge and gradient are compatible for transporting the given sediment load. A subsequent perturbation will cause the river to downcut leaving an erosional bench or strath terrace above the river. The most probable mechanism for incision is tectonism: either the flood plain is uplifted or there is a base-level fall in a downstream reach. It is possible that climate change can also play a role in strath terrace formation if it increases sediment load and forces a degrading stream towards equilibrium. This might be accomplished in areas of gradual uplift where streams are slowly downcutting to maintain a base level of erosion.

There are other strath terraces located along the Gila River and its tributaries upstream from the project area in the Duncan and San Carlos River valleys (Anderson, 1990; Morrison, 1965). These terraces are cut into basin fill and bedrock with the highest terraces situated over 100 m above the river (Table 2). The highest terrace in the San Carlos River valley is 120 m above the San Carlos River and is penecontemporaneous with volcanics K/Ar dated at approximately 3.6 Ma (Anderson, 1990; Reynolds and others, 1986). Downstream from the project area is a Gila River terrace that is covered by a 3.2 My-old basalt flow (Lee and Bell, 1975; Shafiqullah and others, 1980). This terrace is situated only 12 m above the Gila River. It is apparent that the upper reaches of the Gila River system have experienced more downcutting than the lower reaches. This supports the idea of Pliocene-Quaternary uplift in the Central Transition zone and Mexican Highlands physiographic subprovince (Menges and Pearthree, 1989).

Soil-Landform Relationships

Soils were heavily utilized to age estimate and correlate geologic surfaces in the MGR area. Such a strategy is based on the assumption that soils reflect the age of associated landforms, and that the older the landform surface, the more advanced the stage of soil development. This assumption holds true in areas of geomorphic stability, but it may be invalid in areas that have been denuded (Johnson and others, 1990). Insight into landscape stability in the MGR area can be gained by looking at trends in soil development between the different geologic surfaces. Soils presented in Appendix A constitute two soil chronosequences, one for the MGR terraces and one for the Florence fan-complex. A soil chronosequence is a series of soils that vary in morphology and chemistry due primarily to age differences (Birkeland, 1984; Harden, 1982). The effects of the nontemporal soil-forming factors (climate, vegetation, topography, and parent material) are considered equal. In reality, climate change during the Quaternary precludes the reality of any true soil chronosequence older than 10 ka, but the idea is that time is the most influential factor is soil development within the chronosequence. The MGR terrace and Florence fan-complex soil chronosequences help to define soil-landform relationships in the region (e.g., Glock, 1991) and provide a reference for future correlation of geologic surfaces in south-central Arizona.

The MGR terrace and Florence fan-complex soil chronosequences are based on field descriptions only. In the MGR area, the pedologic properties most indicative of surface age are $CaCO_3$ morphology, texture, and to a lesser degree, reddening and accumulation of secondary silica. How these properties vary between different geologic surfaces is presented below. It should be pointed out that depth of pedogenesis is as important as any morphological property in reflecting soil age, and that in places, the full soil profile could not be exposed by hand. This was especially true where petrocalcic horizons occur near the surface. Consequently, the thickness and presence of some pedologic features may be under-represented on older surfaces.

Calcium Carbonate

Calcium carbonate morphology changes in a predictable manner through time (Gile and others, 1966; Machette, 1985) and is thus a very useful pedologic property for estimating relative soil age in the field (Birkeland and others, 1990; Harden and others, 1991; Pewe, 1978). With other soil forming factors equal, soils should progress from Stage I to VI $CaCO_3$ morphology through time. Rates of calcium carbonate accumulation will vary on a local scale, however, due to other nontemporal soil-forming factors, e.g., amount of limestone in the parent material or amount of dust influx. Within each chronosequence, these factors are considered approximately equal amongst the soils. Another factor is soil texture; given an equal amount of $CaCO_3$ in coarse and fine textured soils, the $CaCO_3$ morphology stage will be higher in the former due to lesser porosity. With the exception of the Adamsville Terrace, most of the soils within the chronosequences have comparable, primary textures that are sand and gravel dominant.

Within the MGR terrace chronosequence, $CaCO_3$ morphology varies from I to IV+ (Table 3). On the Adamsville Terrace, $CaCO_3$ is disseminated and generally not visible. However, fine (< 1 cm) rhizoliths of $CaCO_3$ do occur at approximately one meter depth. These rhizoliths were not visible in the field and were identified only after wet sieving the sediment with a 355 micrometer screen. Stiles Terrace alluvium contains fine (2-4 mm) nodules nodules of $CaCO_3$ (Stage II). In the Bogart Terrace, $CaCO_3$ occurs as filaments and small (< 1 cm) masses (Stage II+). Florence Terrace soils contain a variety of $CaCO_3$ morphologies depending on the degree of surface erosion. The more stable Florence Terrace surfaces contain soils where the matrix is plugged with $CaCO_3$ and laminar calcareous caps form near the surface. On more degraded parts of the Florence Terrace, $CaCO_3$ only forms thin, discontinuous rinds on clasts. All three strath terraces have at least Stage III $CaCO_3$ morphologies.

Soils within the Florence fan-complex also show a progressive sequence of calcification (Table 3). Ya1 soils contain discontinuous rinds of $CaCO_3$ on the bottom sides of stones (Stage I). Ma2 soils contain horizons where $CaCO_3$ coats gravels and indurates much of the pore space (Stage II+). Ma1 and Oa soils contain coarse (> 1 cm) masses and nodules of $CaCO_3$ over a petrocalcic horizon with a laminar cap (Stage IV).

Table 3. Soil Classification, color, calcium carbonate development, and Profile Development Index (PDI) for geologic surfaces.

Aggradational Terraces

	Y1	M3	M2	M1	O
Classification	Torrifluvents Camborthids	Calciorthids Torrifluvents	Calciorthids	Calciorthids Paleorthids Paleargids	Durorthids Paleorthids
Hue	10 YR	7.5 - 10 YR	7.5 YR	5 - 7.5 YR	7.5 YR
CaCO3 Stage	I	II	II+	III - IV	IV+
PDI (Profile #)	-	.07 (MGR-23) .21 (MGR-9)	.22 (MGR-12)	.03 (MGR-22) .19 (MGR-10surface) .43 (MGR-15) .51 (MGR-10buried)	.63 (MGR-11)

Strath Terraces

	Ms3	Ms2	Ms1
Classification	Calciorthid Paleorthids	Paleargid	Durorthid
Hue	7.5 YR	5 - 7.5 YR	7.5 - 10 YR
CaCO3 Stage	III+	III+	IV+
PDI (Profile #)	.43 (MGR-26)	.44 (MGR-24)	.64 (MGR-25)

Alluvial Fans

	Ya1	Ma2	Ma1	Oa
Classification	Camborthids Torrifluvents	Calciorthids Camborthids Haplargids	Calciorthids Paleorthids Haplargids	Paleargids Paleorthids
Hue	7.5 - 10 YR	7.5 - 10 YR	7.5 YR	2.5 - 7.5 YR
CaCO3 Stage	I	II+	III - IV	IV+
PDI (Profile #)	0.13 (MGR-17)	0.40 (MGR-19)	0.46(MGR-16)	0.52(MGR-18)

Texture

With time, the ratio of fine to coarse sediment increases within a soil profile due to the capture of dust and in situ formation of clays (Birkeland, 1984). In arid environments, it is argued that dust influx is more important than in situ clay formation in changing soil texture through time, especially in coarse-textured, Holocene soils (Harden and others, 1991). With finer textured Holocene soils, it is uncertain how much aerosolic dust penetrates the solum. In contrast, a considerable portion of the clay in older desert soils may be relict from moister conditions during glacial climate (Glock, 1991; Shlemon, 1978). Together, the effect of these processes is a higher silt+clay to sand ratio through time. Hence, texture can be used to compare soil age provided that primary parent materials are comparably textured.

Parent material controls the texture of Adamsville Terrace soils, and there is no evidence of pedogenic modification of the primary bedding other than by vertical mixing via bioturbation. There is also little evidence of textural modification in the Stiles Terrace; intact primary bedforms indicate that the parent material is relatively intact. The Bogart Terrace contains evidence of increased silt and clay in the upper 30 cm resulting in loamy textures and slightly plastic consistence when wet. Soil texture is quite variable in the Florence Terrace. Some of this variability is attributable to the original bedded parent material (e.g., Soil MGR-15), but there is also considerable pedogenic modification of texture as exemplified by the buried paleosol at MGR-10. Here, a clay-rich, argillic horizon is developed into cobbles and gravels. The Target Terrace contains soils with clay-loam textures above the petrocalcic horizon. The textures in the surface horizon are partly if not mostly inherited from eolian dust and do not reflect the age of the underlying soil. Fragments of petrocalcic horizon at the surface indicate that the Bkm horizon has been eroded and buried by subsequent sediment.

Of the MGR strath terraces, Ms2 contains the most clay-enriched soil (MGR-24). The Bt horizons in this soil contain > 50% clay (field-estimated) and prominent clay skins. The younger Ms3 soil and the older Ms1 soil show less evidence of textural modification. Limited textural modification in the Ms3 soil may reflect its younger age, although given the presence of a Bkm horizon, one would expect more textural modification in the overlying horizon. Perhaps the original Bt horizon has been eroded and replaced with eolian sediment. Erosion of the Bt horizon is clearly indicated for the Ms1 soil where large fragments of petrocalcic horizon are common at the surface.

Soils within the Florence fan-complex display the most uniform trend in increasing clay content with time. Textures in Ya1 soils are mostly gravelly coarse sands, much like that of adjacent washes. In contrast, Ma2 soils have more silt and clay and loamy textures. Ma1 soils contain clay loam textures, and Oa soils contain gravelly clay.

Rubification (Soil Reddening)

Under well-drained conditions, soils typically become redder with time, a process known as rubification. Most of the red color comes from the production of iron oxyhydroxides produced by chemical weathering (McFadden and Hendricks, 1985). Rubification is most pronounced in soils that are well leached and oxygenated. Leaching is inhibited in arid and semiarid environments due to limited rainfall, and as a result, salts like $CaCO_3$ tend to accumulate in the soil. This masks iron oxyhydroxides and obscures rubification. Although MGR area soils are calcareous, there is still an overall progression of rubification in increasingly older soils (Table 3). The Adamsville and Stiles terrace soils have 10YR hues, whereas the Bogart, Florence, and Target soils have 7.5YR and 5YR hues. In contrast, rubification is not progressive in the strath terraces. The reddest soil is on Ms2, and the least red soil is on Ms1. Again this supports the interpretation that the original Bt on Ms1 has been eroded and replaced by Holocene eolian sediment. Soils developed in the Florence fan-complex generally show a progression in rubification. Moreover, these soils tend to be a little redder than the MGR terrace soils, possibly as a result of greater iron content in the granitic parent material. Oa soils are the reddest with 2.5YR hues.

Secondary Silica

Accumulation of secondary silica is common in arid and semiarid soils developed into silica-rich parent material, e.g., rhyolitic volcanics (Soil Survey Staff, 1975:41). Secondary silica is produced in soil via chemical weathering of alumino-silicate minerals, translocation, and precipitation (Chadwick and others, 1989). Like $CaCO_3$, there is a progressive sequence of silica accumulation in progressively older soils (Harden and others, 1991). In the MGR area, however, secondary silica is generally found only in the Target Terrace and Ms1 soils. This suggests that these soils are considerably older than any of the other soils in the area. It is possible that secondary silica accumulations occur in some of the Florence Terrace soils as suggested by the Soil Conservation Service mapping of Durorthids in places on this surface on the north side of the MGR (Hall, 1991). Field observations by the author, however, indicate that such soils are not representative of the Florence Terrace. It should be noted that secondary silica is difficult to identify in the field when it coexists with $CaCO_3$. On the Target Terrace and Ms1, secondary silica occurs within the petrocalcic horizon. The silica tends to be light brown and contrasts with the more white $CaCO_3$. In some instances, the secondary silica is sufficiently segregated from the $CaCO_3$ that it can be distinguished with a dilute hydrochloric acid test. In other instances, it can only be distinguished in the laboratory (see Soil Survey Staff, 1975). Soils developed into the Florence fan-complex do not contain secondary silica.

Index of Soil Profile Development

A modified version of the Harden Index of soil profile development (Harden, 1982; Birkeland and others, 1990) was used to quantify soil development. A weighted profile development index (PDI) was calculated for soils on the MGR terraces (except the Adamsville Terrace) and for soils on the Florence fan-complex. A PDI value was not calculated for Adamsville Terrace soils due to the fact that stratified parent materials generate high PDI values that do not reflect pedogenesis. The following soil characteristics were indexed: rubification, lightening, total texture, dry consistence, structure, carbonate morphology, and secondary silica. Parent material values for the MGR terrace chronosequence were determined from sediment in the modern MGR channel. Parent material values for the Florence fan-complex chronosequence were determined from sediment in adjacent washes. Procedures for deriving horizon and profile development indices presented by Harden (1982) were used with the following modifications. For rubification and color lightening, only dry hue and chroma were used. If the value was negative, i.e., the hue and chroma were less than that of the parent material, it would be adjusted to zero. PDI values were weighted by dividing by the depth of the profile (see Birkeland and others, 1990). Total texture and structure were not counted for Bkm and Bkqm horizons. An arbitrary depth of 50 cm was assigned to cemented horizons that could not be excavated by hand. For the MGR terrace soils, a horizon index value of 1.0 was assigned to Bkqm horizons due to the presence of secondary silica. The resulting PDI values should only be used for comparison within and not between chronosequences, i.e., the PDI's of terrace and fan soils should not be compared.

In areas with a history of geomorphic stability, PDI values should increase progressively within a soil chronosequence. Such a pattern exists in the Florence fan-complex where PDI values progress from 0.13 to 0.52 between the Ya1 and Oa surfaces (Table 3). This suggests that the soils in the Florence fan-complex are relict and have not been substantially modified since deposition of their parent materials. In contrast, there is considerable variability in the PDI values of soils both within and between different terrace surfaces. Variability in PDI values within a terrace surface is exemplified by the Stiles Terrace where soil profile MGR-23 has a value of 0.07 and MGR-9 has a value of 0.21. This is believed to reflect the fill-cut structure of this landform and the resulting mosaic of Stiles Terrace soils (Holocene) and truncated Florence Terrace soils (Pleistocene) on the Stiles Terrace tread. The Bogart Terrace soil has a PDI of 0.22 which is comparable to PDI values of some surface soils on the Florence Terrace (0.19). The Florence Terrace has the greatest variability in PDI values reflecting its differential preservation of surfaces. The buried soil at MGR-15 has a high PDI value of 0.51 indicating that this buried surface was exposed for a considerable time and is well preserved. The Target Terrace soils have a PDI value of 0.63; this value would be larger if the original Bt horizon were preserved and if the full depths of these soils were defined. The same is true for the Ms1 soil whose PDI is 0.64. Surprisingly, Ms3 contains a relatively mature soil with a PDI of 0.43. Advanced pedogenic maturity on this low terrace may suggest that the rate of MGR downcutting has slowed since the formation of the Ms3 tread. The absence of an ideal progression of PDI values with increasing surface age indicates that many of the MGR stream terraces are considerably degraded.

In sum, the PDI values suggest that many of the older surfaces in the MGR area are denuded and that original surfaces are seldom preserved. This is congruent with overall topography: older MGR stream terraces are significantly dissected and seldom retain their planar terrace form. Consequently, the suite of soils on the MGR terrace sequence represent a discontinuous chronosequence, and caution should be used in correlating these older surfaces using soils. The Florence fan-complex represents a more complete soil chronosequence and suggests relatively greater surface stability as compared to the MGR terraces.

Summary

Five alluvial fan surfaces and 12 stream terrace surfaces have been identified as temporally discrete entities in the MGR area. These surfaces are the product of alternating erosion and deposition by the MGR and its tributaries extending as far back as the late Pliocene. The youngest surfaces in the MGR area (Ya2, Ya1, Y2, Y2/Y1, and Y1) may still be aggrading and are subject to flooding at 100-year timescales.

Downstream converging MGR terraces and progressively increased stream dissection to the east may be the products of tectonic uplift to the east. Late Cenozoic denudation of the Central Transition zone and Mexican Highlands physiographic subprovince in Arizona may be generating isostatic rebound. Quaternary isostatic rebound in otherwise tectonically inactive areas have been hypothesized for Arizona (Menges and Pearthree, 1989) and elsewhere (Bishop and Brown, 1992). Further geomorphic studies in the marginal zone between the Colorado Plateau and Basin and Range provinces may provide further insight into this provocative hypothesis.

Soils remain a most viable line of evidence for relative age dating and correlation of geologic surfaces. However, the two soil chronosequences presented here show that many depositional landforms have been subsequently eroded, and that associated soils may not reflect the true age of the landform. In using soils in surficial geologic mapping, care should be given in relating soils to discrete surfaces. One should be cognizant of evidence for previous surface erosion such as fragments of pedogenic $CaCO_3$ at the surface. If soils are used in conjunction with other physical evidence, e.g., topographic position, surface morphometry, stream dissection, etc.), then relative age dating and surface correlations will be more accurate.

Finally, it is important that the surface age estimates presented here be tested by independent dating methods. For Holocene and latest Pleistocene surfaces, radiocarbon-datable material should be collected when encountered in the field. For older surfaces, numerical age estimation is more problematic. Most Quaternary dating methods are presently in the developmental stage. However, as these are refined, they should be applied to surface chronologies presented here and elsewhere in Arizona. As surface chronologies become more refined, then geologic hazard assessment and general land-use management decisions can be made with greater confidence.

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Appendix A: Soil Descriptions

Geologic Surface: Yal
Soil Profile: MGR-17
Classification: Camborthid
Location: Pinal County, Arizona; NW 1/4, SW 1/4, Sec. 34, T. 4 S., R. 10 E.
Physiographic Position: alluvial fan; elevation 500 m.
Topography: Gentle 1% slope
Vegetation: Bursage (*Franseria*), ironwood (*Olneya*), palo verde (*Cercidium*), saguaro (*Cereus*).
Sampled by: Gary Huckleberry, September 8, 1992.
Remarks: Soil pit excavated approximately 35 m east of section road. Coarse stratification still evident in Bk2. Cambic horizon based on color. Surface contains discontinuous lag of gravel-sized grus. Soil colors are for dry conditions.

A 0-2 cm. Light yellowish brown to yellowish brown (10YR 5.5/4) gravelly loamy coarse sand; weak, fine, granular to subangular blocky structure; soft (dry), nonsticky and nonplastic (wet); noneffervescent; clear smooth boundary.

Bw 2-22 cm. Brown to light brown (7.5YR 5.5/4) gravelly loamy coarse sand; weak, fine to medium, subangular blocky structure; soft (dry), nonsticky and nonplastic (wet); noneffervescent; gradual smooth boundary.

Bk1 22-45 cm. Light brown (7.5YR 6/4) gravelly coarse sand; single grain to weak, medium, subangular blocky structure; loose to soft (dry), nonsticky and nonplastic (wet); slightly effervescent; carbonates occur as discontinuous rinds on the bottoms of clasts (Stage I); gradual smooth boundary.

Bk2 45-90+ cm. Light brown (7.5YR 6/4) gravelly coarse sand; single grain; loose (dry), nonsticky and nonplastic; slightly effervescent; carbonates occur as discontinuous rinds on the bottoms of clasts (Stage I).

Geologic Surface: Ma2
Soil Profile: MGR-19
Classification: Calciorthid
Location: Pinal County, Arizona; NE 1/4, NW 1/4, Sec. 12, T. 5 S., R. 9 E.
Physiographic Position: Distal end of alluvial fan; elevation 473 m.
Topography: Gentle 1 % slope.
Vegetation: Creosote (*Larrea*), and assorted grasses.
Sampled by: Gary Huckleberry, September 15, 1992.
Remarks: Soil pit excavated within median at the intersection of Highway 89 and its business route between the Florence-Casa Grande and CAP canals. Surface contains algal crusts and lag of grussy gravels (< 1 cm). Also at surface are Hohokam artifacts. Soil colors are for dry conditions.

A 0-1 cm. Very pale brown (10YR 7/3) gravelly loamy medium sand; single grain; loose (dry), nonsticky and nonplastic (wet); violently effervescent; carbonates are disseminated; clear smooth boundary.

Bk1 1-10 cm. Very pale brown (10YR 7/3) loamy fine sand; single grain; loose (dry), nonsticky and nonplastic; violently effervescent; carbonates are disseminated; clear smooth boundary.

Bk2 10-19 cm. Very pale brown (10YR 7/3) sandy loam; single grain to weak, fine, subangular blocky structure; loose to soft (dry), slightly sticky and slightly plastic (wet); violently effervescent; carbonates occur as small (< 5 mm) masses (Stage I); abrupt smooth boundary.

Bk3 19-70+ cm. Pinkish gray (7.5YR 7/4) and pinkish white (7.5YR 8/2) sandy loam; massive; very hard (dry), sticky and slightly plastic (wet); violently effervescent; carbonates occur as large, irregular masses (Stage II+).

Geologic Surface: Ma1
Soil Profile: MGR-16
Classification: Paleorthid
Location: Pinal County, Arizona; SW 1/4, SE 1/4, Sec. 34, T. 4 S., R. 10 E.
Physiographic Position: alluvial fan; elevation 519 m.
Topography: Gentle 1% slope
Vegetation: Bursage (*Franseria*), ironwood (*Olneya*), palo verde (*Cercidium*), saguaro (*Cereus*).
Sampled by: Gary Huckleberry, September 8, 1992.
Remarks: Soil pit excavated approximately 14 m north of section road. Surface contains discontinuous veneer of gravel-sized grus. Soil mounds extending 5-10 cm above the surface are common around shrubs. Fan gravels are generally granitic and angular although one spherical cryptocrystalline cobble (5 cm in diameter) was located at approximately 40 cm depth. Bw horizon defined by color. Soil colors are for dry conditions.

A — 0-1 cm. Light brown to reddish yellow (7.5YR 6/5) gravelly sandy loam; weak, fine, granular structure; loose to soft (dry), nonsticky and slightly plastic (wet); noneffervescent; clear smooth boundary.

A/Bw — 1-12 cm. Reddish yellow (7.5YR 6/6) gravelly sandy loam; weak, fine to medium, subangular blocky structure; soft (dry), nonsticky and slightly plastic (wet); noneffervescent; gradual smooth boundary.

Bk1 — 12-45 cm. Reddish yellow (7.5YR 6/5) gravelly sandy loam; weak, medium, angular blocky structure; soft (dry), slightly sticky and slightly plastic (wet); violently effervescent; carbonates are disseminated; clear smooth boundary.

Bk2 — 45-64 cm. Reddish yellow (7.5YR 6/5) very gravelly sandy clay loam; weak, fine, subangular blocky structure; soft (dry), nonsticky and slightly plastic (wet); noneffervescent; carbonates are disseminated; clear smooth boundary.

Bk3 — 64-88 cm. Pink (7.5YR 7/4) very gravelly sandy clay loam with many, coarse, distinct, pink (7.5YR 8/2) mottles; weak, fine, angular blocky structure; slightly hard (dry), slightly sticky and plastic (wet); violently effervescent; carbonates occur as coarse mottles and nodules (Stage II+); abrupt smooth boundary.

Bkm — 88-92+ cm. Pink (7.5YR 8/2); massive; extremely hard; violently effervescent; carbonates completely indurate horizon, laminar top (Stage IV).

Geologic Surface: Oa
Soil Profile: MGR-18
Classification: Paleargid
Location: Pinal County, Arizona; SE 1/4, SW 1/4, Sec. 33, T. 4 S., R. 11 E.
Physiographic Position: Ridge of relict alluvial fan; elevation 620 m.
Topography: 1-2 % slope
Vegetation: Bursage (*Franseria*), palo verde (*Cercidium*), creosote (*Larrea*), assorted grasses.
Sampled by: Gary Huckleberry, September 15, 1992.
Remarks: Soil pit excavated approximately 100 m northwest of the intersection of Hawkview and Whitlow Ranch roads on top of ridge next to a two-track road. Variable cobble lithologies at surface including granite, basalt, andesite porphyry, and hematite. Lag of grussy gravels (< 1 cm) at surface; no pavement. Soil colors are for dry conditions.

A 0-2 cm. Light brown (7.5YR 6/4) gravelly loamy coarse sand; weak, fine, subangular blocky structure; slightly hard (dry), nonsticky and nonplastic (wet); noneffervescent; clear smooth boundary.

Bt 2-40 cm. Red (2.5YR 4/6) gravelly sandy clay; weak, fine to medium, angular blocky structure; hard (dry), slightly sticky and slightly plastic (wet); noneffervescent; abrupt smooth boundary.

Bkm 40-45+ cm. White (5YR 8/1); extremely hard; violently effervescent; carbonates completely indurate horizon, laminar top (Stage IV).

Geologic Surface: Y1
Soil Profile: MGR-14
Classification: Torrifluvent
Location: Pinal County, Arizona; SW 1/4, NW 1/4, SE 1/4, Sec. 5, T. 5 S., R. 9 E.
Physiographic position: Gila River stream terrace; elevation 438 m
Topography: level; < 1 % slope
Vegetation: Historically dominated by mesquite (*Prosopsis*); presently cultivated.
Sampled by: Gary Huckleberry, July 30, 1992.
Remarks: Backhoe trench was excavated between cotton fields. Area was inundated during October, 1983 flood. Primary bedforms are largely destroyed by bioturbation and plowing; worm and insect burrows and pellets are common in the Ap2 and 2C horizons. Peds of 4C horizon break along primary bedding planes. Common white filaments at 104-112 cm. 5Cox is redder than overlying deposits. Colors are for dry and moist soil; the latter is denoted by "m".

Ap1 0-28 cm. Pale brown (10YR 6/3) and brown to dark brown (m10YR 4/3) silty clay loam; moderate, very coarse, angular blocky structure; hard (dry), friable (moist), sticky and slightly plastic (wet); violently effervescent; gradually smooth boundary.

Ap2 28-45 cm. Pale brown (10YR 6/3) and mixed brown to dark brown (m7.5YR 4/2) and light yellowish brown (m10YR 6/4) silty clay and very fine sandy loam; weak, coarse, angular blocky structure; slightly hard (dry), firm (moist), very sticky and very plastic (wet); violently effervescent; abrupt smooth boundary.

2C 45-65 cm. Grayish brown (10YR 5/2) and mixed brown to dark brown (m7.5YR 4/2) and light yellowish brown (m10YR 6/4) silty clay and very fine sandy loam; weak, medium, angular blocky structure; slightly hard (dry), friable (moist), very sticky and very plastic (wet); strongly effervescent; abrupt smooth boundary.

3C 65-74 cm. Pale brown (10YR 6/3) and brown to dark brown (m7.5YR 4/2) silty clay; weak, medium, angular blocky structure; very hard (dry), friable (moist), very sticky and very plastic (wet); strongly effervescent; abrupt smooth boundary.

4C 74-120 cm. Pale brown (10YR 4.5/3) and dark brown (m7.5YR 3/4) very fine sand; massive; loose (dry), very friable (moist), slightly sticky and slightly plastic (wet); strongly effervescent; abrupt smooth boundary.

5Cox 120-160+ cm. Pale brown (10YR 4.5/3) and brown to dark brown (m7.5YR 4/4) very fine sandy loam; massive; loose (dry), friable (moist), sticky and slightly plastic (wet); strongly effervescent.

Geologic Surface: Ye
Soil Profile: MGR-21
Classification: Torripsamment
Location: Pinal County, Arizona; SE1/4, SW 1/4, NE 1/4, Sec. 19, T. 4 S., R. 10 E.
Physiographic Position: Sand dune on eroded Gila River terrace; elevation 473 m.
Topography: > 30 % slope on dune faces; level on crest.
Vegetation: Creosote (*Larrea*), cholla (*Opuntia*); assorted grasses.
Sampled by: Gary Huckleberry, October 13, 1992.
Remarks: Soil pit excavated at crest of dune. Artifacts exposed at surface in places. The AC horizon is slightly darker, and there is slight reddening below 40 cm depth, but these could not be distinguished with the Munsell color book. AC contains many fine roots whereas C contains few coarse roots. Colors are for dry soil.

AC 0-10 cm. Grayish brown to light brownish gray (2.5Y 5.5/2) fine sand; single grain (dry), not sticky and not plastic (wet); noneffervescent; clear smooth boundary.

C 10-80+ cm. Grayish brown to light brownish gray (2.5YR 5.5/2) fine sand; single grain (dry), not sticky and not plastic (wet); noneffervescent.

Geologic Surface: M3 (Stiles Terrace)
Soil Profile: MGR-23
Classification: Torrifluvent
Location: Pinal County, Arizona; SW 1/4, SE 1/4, NW 1/4, SW 1/4, Sec. 19, T. 4 S., R. 10 E.
Physiographic Position: Gila River terrace; elevation 461 m.
Topography: level; slope < 1 %
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), cholla, and assorted grasses.
Sampled by: Gary Huckleberry, November 4, 1992.
Remarks: Exposed in backhoe trench. Parent material for C1 and C2 horizons is tributary alluvium; parent material for 2Bk and 3C horizons is Gila River alluvium. Primary bedforms are preserved in all horizons. 2Bk horizon contains slightly hard nodules of $CaCO_3$ (2-4 mm in diameter). Colors are for dry soil.

C1 0-40 cm. Pale brown (10YR 6/3) loamy fine sand; single grain; loose (dry), not sticky and not plastic (wet); violently effervescent; carbonates are disseminated; abrupt smooth boundary.

C2 40-78 cm. Pale brown (10YR 6/3) loamy fine sand; single grain; loose (dry), not sticky and not plastic (wet); violently effervescent; carbonates are disseminated; abrupt smooth boundary.

2Bk1b 78-110 cm. Very pale brown to pale brown (10YR 6.5/3) loamy fine sand with common, fine, distinct white (10YR 8/2) mottles; strong, medium, angular blocky structure; hard (dry), not sticky and not plastic (wet); violently effervescent; carbonates occur as horizontal seams and nodules (Stage II); clear smooth boundary.

2Bk2b 110-154 cm. Pale brown (10YR 6/3) loamy fine sand; weak, medium, angular blocky to platy structure; slightly hard (dry), not sticky and not plastic (wet); violently effervescent; carbonates are disseminated; clear smooth boundary.

3C 154-210+ cm. Pale brown (10YR 6/3) loamy fine sand and fine sand; single grain and massive; loose (dry), not sticky and not plastic (wet); strongly effervescent.

Geologic Surface: M3 (Stiles Terrace)
Soil Profile: MGR-9
Classification: Calciorthid
Location: Pinal County, Arizona; SW 1/4, SW 1/4, SW 1/4, Sec. 19, T. 4 S., R. 10 E.
Physiographic Position: Gila River terrace; elevation 459 m.
Topography: level; slope < 1 %.
Vegetation: Creosote (*Larrea*), and assorted grasses.
Sampled by: Gary Huckleberry, May 20, 1992.
Remarks: Soil exposed in pre-existing pit. Algal crusts are common at surface. Mounds of fine sand and silt at base of shrubs. Very thin, discontinuous A horizon. Bk horizon still contains primary bedforms such as faint silt laminae and coarse sand lenses. Carbonates in Bk are at an incipient stage of development. Carbonates do not cement matrix in 2Bk2 and 2Bk3 horizons. Colors are for dry soil.

Bk 0-12 cm. Pale brown (10YR 6/3) gravelly medium loamy sand; weak, medium subangular blocky structure; soft (dry), not sticky and not plastic (wet); slightly effervescent; carbonates occur as discontinuous rinds on bottoms of clasts (Stage I); abrupt smooth boundary.

2Bk1 12-25 cm. Pale brown to very pale brown (10YR 6.5/3) fine loamy sand; weak, medium, subangular blocky structure; soft (dry), not sticky and not plastic (wet); strongly effervescent; carbonate rinds on top and bottom of clasts (Stage II); distinct, smooth boundary.

2Bk2 25-42 cm. Very pale brown (10YR 7.5/3) fine loamy sand; weak, medium, angular blocky structure; soft (dry), not sticky and not plastic (wet); violently effervescent; carbonates engulf clasts and extend through matrix (Stage II+); abrupt smooth boundary.

2Bk3 42-150+ cm. Pale brown (10YR 6/3) cobbles with medium sand matrix; single grain; loose (dry), not sticky and not plastic (wet); violently effervescent; carbonates engulf clasts and extend through matrix (Stage II+).

Geologic Surface: M2 (Bogart Terrace)
Soil Profile: MGR-12
Classification: Calciorthid
Location: Pinal County, Arizona; SE 1/4, SW 1/4, NW 1/4, Sec. 8, T. 5 S., R. 9 E.
Physiographic Position: interfluve on dissected Gila River terrace; elevation 439 m.
Topography: level; slope < 1 %.
Vegetation: Creosote (*Larrea*), and assorted grasses.
Sampled by: Gary Huckleberry, June 18, 1992.
Remarks: Soil pit excavated into interfluve. Surface has 60 % cover of mostly angular gravels and pebbles with some fractured, rounded Gila River cobbles. Clasts are predominantly volcanic and metavolcanic. Petrocalcic fragments are common at the surface. Few Gila River cobbles encountered while digging. The Bk3 horizon is cemented with some noncalcareous precipitate, perhaps iron oxyhydroxides. Colors are for dry soil.

Bk1 0-30 cm. Light brown (7.5YR 6/4) gravelly sandy loam; single grain to weak, fine, subangular blocky structure; soft (dry), nonsticky and slightly plastic (wet); violently effervescent; carbonates are disseminated; abrupt smooth boundary.

Bk2 30-48 cm. Pink (5YR 7/3) gravelly loamy fine sand with many, medium, faint, reddish brown to yellowish red (5YR 5/5) mottles; massive; extremely hard (dry), nonsticky and nonplastic (wet); violently effervescent (Stage II); carbonates occur as filaments and small (< 1 cm) masses; abrupt smooth boundary.

Bk3 48-70+ cm. Reddish brown to yellowish red (5YR 5/5) fine to medium sand with faint pink (5YR 7/3) mottles; massive; extremely hard (dry), nonsticky and nonplastic (wet); mottles are violently effervescent but matrix is noneffervescent; carbonates occur as segregated, irregular, medium masses (Stage I).

Geologic Surface: M1 (Florence Terrace)
Soil Profile: MGR-10
Classification: Calciorthid
Location: Pinal County, Arizona; NW 1/4, SE 1/4, NE 1/4, Sec. 8, T. 5 S., R. 9 E.
Physiographic Position: Gila River terrace; elevation 445 m.
Topography: level to gently sloping; slope 1-2 %.
Vegetation: Creosote (*Larrea*), and assorted grasses.
Sampled by: Gary Huckleberry, June 8, 1992.
Remarks: Soils exposed in abandoned gravel quarry. 0-200 cm of profile is from an exposure facing west. 350-490 cm of profile is from a south-facing exposure located ca. 100 m to the west of the first exposure. 490-800 cm of profile is covered by talus. Desert pavement covers 70-90% of surface on stable parts of the terrace tread; clasts are slightly to moderately varnished with no consistent varnish color (varies with lithology). Colors are for dry soil.

Bk1 0-70 cm. Light yellowish brown (7.5-10YR 6/4) gravelly, loamy sand; single grain to weak, fine, subangular blocky structure; loose to soft (dry), not sticky and not plastic (wet); violently effervescent; carbonates occur as thin (< 1 mm), complete rinds (Stage II); gradual, wavy boundary.

Bk2 70-125 cm. Pinkish white (7.5YR 8/2) gravelly, loamy coarse sand with common, coarse to fine, distinct, light yellowish brown (7.5-10YR 6/4) mottles; weak, medium to coarse, angular blocky structure; mixed soft and very hard (dry), not sticky and not plastic (wet); violently effervescent; carbonates occur throughout matrix and as 1-2 mm rinds on stones (Stage III+); clear wavy boundary.

Bk3 125-170 cm. Mixed pinkish white (7.5YR 8/2) and light yellowish brown (7.5-10YR 6/4) gravelly, loamy coarse sand; single grain to weak, medium, subangular blocky structure; mixed soft and very hard (dry), not sticky and not plastic (wet); violently effervescent; carbonates are irregularly disseminated in matrix with common, large (2 cm) nodules (Stage II+); clear wavy boundary.

Bk4 170-200+ cm. Light yellowish brown (7.5-10YR 6/4) very gravelly, coarse sand; single grain; loose (dry), not sticky and not plastic (wet); strongly effervescent; carbonates occur as discontinuous rinds on bottom of clasts (Stage I).

2Bt 350-490+ cm. Reddish brown (5YR 4/4) sandy clay matrix in cobbles; single grain; matrix is slightly hard (dry), sticky and slightly plastic (wet); noneffervescent.

3Bkm 800-950+ cm. Cobbles cemented in pinkish white (7.5YR 8/2) carbonate matrix; massive; violently effervescent (Stage III+).

Geologic Surface: M1 (Florence Terrace)
Soil Profile: MGR-15
Classification: Calciorthid
Location: Pinal County, Arizona; SW 1/4, SW 1/4, SE 1/4, Sec. 7, T.5 S., R. 9 E.
Physiographic Position: Gila River terrace; elevation 442 m.
Topography: level to gentle slopes; slope 1- 2 %.
Vegetation: Creosote (*Larrea*) and bursage (*Franseria*).
Sampled by: Gary Huckleberry, September 1, 1992.
Remarks: Soil exposed in roadcut of Highway 287. Exposure cuts into rounded interfluve of eroded Florence Terrace. Bogart Wash is to the west. Tread contains moderate desert pavement and weak rock varnish development. Few surface cobbles have discontinuous carbonate rinds. Manganese oxyhydroxides discontinuously coat ped surfaces in 2Btk1 and 2Btk2. Weak clay skins evident in 2Btk1 and 2Btk2. Colors are for dry conditions.

Bw 0-18 cm. Light brown (7.5YR 6/4) gravelly sandy loam; weak, medium, subangular blocky structure; loose to soft (dry), slightly sticky and slightly plastic (wet); strongly effervescent; clear smooth boundary.

Bk1 18-48 cm. Light brown (7.5YR 6/4) sandy clay loam with many, medium, prominent, pinkish white (7.5YR 8/2) mottles; weak, coarse, angular blocky structure; slightly hard (dry), sticky and plastic (wet); violently effervescent; carbonates occur as nodules and irregular masses (< 1 cm) (Stage II); clear smooth boundary.

Bk2 48-65 cm. Light brown (7.5YR 6/4) sandy clay loam; massive; soft (dry), sticky and plastic (wet); violently effervescent; carbonates occur as very fine filaments (Stage I); abrupt smooth boundary.

2Bk1b 65-90 cm. Pink (7.5YR 7/4) clay loam with many, coarse, prominent, pinkish white (7.5YR 8/2) mottles; strong, coarse to very coarse, platy structure; extremely hard (dry), sticky and plastic (wet); violently effervescent (carbonates occur as irregular laminar masses (1-2 cm thick) (Stage III); clear smooth boundary.

2Bk2b 90-110 cm. Light brown (7.5YR 6/4) silty clay with common to many, medium, prominent, pinkish white (7.5YR 8/2) mottles; strong, coarse, angular blocky structure; hard to extremely hard (dry), very sticky and plastic (wet); strongly effervescent; carbonates occur as irregular masses and nodules (1 cm) (Stage II); gradual smooth boundary.

2Btk1b 110-145 cm. Light brown (7.5YR 6/4) silty clay with common to many, medium, prominent, pinkish white (7.5YR 8/2) mottles; strong, medium, angular blocky structure; extremely hard (dry), very sticky and plastic (wet); strongly effervescent; carbonates occur as irregular masses (< 1 cm) (Stage II); gradual smooth boundary.

2Btk2b 145-200+ cm. Strong brown (7.5YR 5/6) silty clay with common, fine, prominent, pinkish white (7.5YR 8/2) mottles; strong, medium, angular blocky structure; extremely hard (dry), very sticky and plastic (wet); strongly effervescent; carbonates occur as few filaments (Stage I).

Geologic Surface: M1' (Degraded Florence Terrace)
Soil Profile: MGR-20
Classification: Calciorthid
Location: Pinal County, Arizona; NE 1/4, SW 1/4, SE 1/4, Sec. 24, T. 4 S., R. 9 E.
Physiographic Position: Eroded Gila River terrace; elevation 458 m.
Topography: Moderately dissected; slopes 1- 2 %.
Vegetation: Creosote (*Larrea*) and bursage (*Franseria*).
Sampled by: Gary Huckleberry, October 13, 1992.
Remarks: Soil exposed in streamcut approximately 30 m north of railroad. Bw and Bk1 enriched in silt relative lower horizons. Bk2 contains siltans that bridge and hold together sand grains; siltans are 7.5YR. Cox contains 7.5YR matrix. 2Bk contains segregated calcium carbonate and very fine (< 2 mm) black (Mn?) mottles; also contains < 1 mm white salts. 2Bk is cemented by something other than carbonate - possibly iron oxyhydroxides. Soil colors are for dry conditions.

Bw 0-12 cm. Pale brown (10YR 6/3) sandy loam; weak, fine, subangular blocky structure; soft (dry), slightly sticky and not plastic (wet); slight effervescence; clear smooth boundary.

Bk1 12-30 cm. Light brownish gray to pale brown (10YR 6/2.5) gravelly loamy sand; single grain; loose (dry), not sticky and not plastic (wet); violently effervescent; carbonates occur as discontinuous rinds on all sides of clasts (Stage I); clear smooth boundary.

Bk2 30-51 cm. Pale brown (10YR 6/3) very gravelly medium sand with light brown (7.5YR 6/4) siltans; single grain; loose (dry), not sticky and not plastic (wet); violently effervescent; carbonates occur as discontinuous rinds on all sides of clasts (Stage I+); clear smooth boundary.

Bk3 51-65 cm. Light brownish gray to pale brown (10YR 6/2.5) gravelly medium sand; single grain, loose (dry), not sticky and not plastic (wet); violently effervescent; carbonates occur as rinds on bottom sides of stones (Stage I); clear smooth boundary.

Bk4 65-95 cm. Pale brown (10YR 6/3) very gravelly medium sand; single grain; loose (dry), not sticky and not plastic (wet); strongly effervescent; carbonates occur as rinds on bottom sides of stones (Stage I); clear smooth boundary.

Cox 95-120 cm. Pinkish gray to light brown (7.5YR 6/3) very gravelly medium sand; single grain; loose (dry), not sticky and not plastic (wet); noneffervescent; abrupt smooth boundary.

2Bk1 120-235 cm. Strong brown (7.5YR 5/6) very fine sand with common, medium, distinct white (7.5YR 8/0) mottles; massive; very hard (dry), slightly sticky and slightly plastic (wet); noneffervescent except for violently effervescent mottles, carbonates occur as segregated, irregular, medium masses (Stage I); clear smooth boundary.

2Bk2 235-270 cm. Strong brown (7.5YR 5/6) very fine sand with common, medium, distinct white (7.5YR 8/0) mottles; massive; hard (dry), slightly sticky and slightly plastic (wet); noneffervescent except for violently effervescent mottles, carbonates occur as segregated, irregular, medium masses (Stage I); clear smooth boundary.

2Bk3 270-295 cm. Strong brown (7.5YR 5/6) very fine sand with few cobbles and common, fine, distinct white (7.5YR 8/0) mottles; massive; very hard (dry), slightly sticky and slightly plastic (wet); noneffervescent except for violently effervescent mottles, carbonates occur as segregated, irregular, medium masses and discontinuous rinds on clasts (Stage I); clear smooth boundary.

3Bk 295-335+ cm. Pinkish gray to pink (7.5YR 7/3) very cobbly fine sandy loam; massive; matrix is soft (dry), slightly sticky and slightly plastic (wet); violently effervescent; carbonates occur as thin discontinuous rinds on clasts and is disseminated in matrix (Stage I+).

Geologic Surface: M1' (Degraded Florence Terrace)
Soil Profile: MGR-22
Classification: Calciorthid
Location: Pinal County, Arizona; SW 1/4, SE 1/4, NW 1/4, SW 1/4, Sec. 19, T. 4 S., R. 10 E.
Physiographic Position: Eroded Gila River terrace; elevation 464 m.
Topography: Slightly dissected; slopes < 1 %.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), cholla (*Opuntia*), and assorted grasses.
Sampled by: Gary Huckleberry, November 4, 1992.
Remarks: Soil exposed in backhoe trench. Av best expressed beneath algal crusts. Parent material is Gila River channel deposits. Soil colors are for dry conditions.

Av 0-2 cm. Brown to pale brown (10YR 5.5/3) loam; moderate, fine, platy structure; soft (dry), slightly sticky and slightly plastic (wet); noneffervescent; abrupt smooth boundary.

Bk1 2-22 cm. Pale brown (10YR 6.5/3) very gravelly loam; massive to single grain; loose (dry); not sticky and not plastic (wet); violently effervescent; carbonates occur as continuous rinds on the bottom sides of stones (Stage I); clear smooth boundary.

Bk2 22-54 cm. Pale brown (10YR 6.5/3) gravels and coarse sand; single grain; loose (dry); not sticky and not plastic (wet); violently effervescent; carbonates occur as continuous rinds on clasts (Stage II); clear smooth boundary.

Bk3 54-110+ cm. Pale brown (10YR 6/3) gravels and coarse sand; single grain; loose (dry), not sticky and not plastic (wet); violently effervescent; carbonates occur as discontinuous rinds on the bottom sides of stones (Stage I).

Geologic Surface: M1' (Degraded Florence Terrace)
Soil Profile: MGR-13
Classification: Calciorthid
Location: Pinal County, Arizona; SE 1/4, SE 1/4, SE 1/4, Sec. 27, T. 4 S., R. 9 E.
Physiographic Position: Eroded Gila River terrace; elevation 439 m.
Topography: Artificially level.
Vegetation: Cultivated
Sampled by: Gary Huckleberry, July 30, 1992.
Remarks: Soil exposed in backhoe trench. Surface was leveled by the Soil Conservation Service during the 1950's. 2Bk contains rounded Gila River gravels. Coarse-textured, felsic and intermediate rocks are deeply weathered and crumble easily. Colors are for moist soil.

Ap 0-42 cm. Yellowish red (5YR 4/6) sandy loam; massive; very friable (moist), slightly sticky and slightly plastic (wet); violently effervescent; abrupt smooth boundary.

Bk 42-115 cm. Yellowish red (5YR 4/6) coarse loamy sand with many, coarse, distinct pinkish gray (7.5YR 7/2) mottles; massive; extremely firm (moist), nonsticky and nonplastic (wet); violently effervescent; carbonates occur as irregular nodules 1-2 cm in diameter (Stage II+); clear smooth boundary.

2Bk 115-140+ cm. Light brown (7.5YR 6/4) gravelly loamy sand; massive to single grain; friable (moist), nonsticky and nonplastic (wet); violently effervescent; carbonates occur as continuous rinds on gravels (Stage II+).

Geologic Surface: O (Target Terrace)
Soil Profile: MGR-11
Classification: Durorthid
Location: Pinal County, Arizona; SW 1/4, NW 1/4, NE 1/4, Sec. 21, T. 4 S., R. 9 E.
Physiographic Position: Gila River terrace; elevation 471 m.
Topography: Slightly dissected; slopes < 1 %.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), and palo verde (*Cercidium*).
Sampled by: Gary Huckleberry, June 8, 1992.
Remarks: Soil exposed in pit excavated adjacent to exploratory well. Carbonates in Av and Bk1 are disseminated. Terrace tread has desert pavement with interlocking stones covering approximately 90% of surface. Black Mn varnish is common on top of clasts; orange Fe varnish is common on bottoms of clasts. Varnish color generally varies with clast lithology. Bkqm fragments are very common at surface. In 2Bkqm horizon, some granites are saprolitic, and some cryptocrystalline rocks are fractured. Largest cobble in profile has 15 cm diameter. Colors are for dry soil.

Av 0-4 cm. Light brown (7.5YR 6/4) silty clay; weak, medium, angular blocky structure; slightly hard (dry), sticky and plastic (wet); violently effervescent; clear smooth boundary.

Bk1 4-16 cm. Light brown (7.5YR 6/4) sandy clay loam; weak, fine, subangular blocky structure; slightly hard (dry), sticky and plastic (wet); strongly effervescent; clear smooth boundary.

Bk2 16-40 cm. Light brown (7.5YR 6/4) gravelly sandy clay loam with many, coarse, distinct pinkish white (7.5YR 8/2) mottles; weak, fine to medium, subangular blocky structure; slightly hard to hard (dry), sticky and plastic (wet); violently effervescent; carbonates occur as continuous 1-3 mm rinds (Stage II+); abrupt smooth boundary.

2Bkqm 40-120+ cm. White to pinkish white (7.5YR 8/1) gravels and cobbles; massive; extremely hard (dry); violently effervescent; carbonates engulf matrix and are laminar at top of horizon (Stage IV+).

Geologic Surface: Ms3
Soil Profile: MGR-26
Classification: Paleorthid
Location: Pinal County, Arizona; SW 1/4, NE 1/4, NW 1/4, Sec. 15, T. 4 S., R. 11 E.
Physiographic Position: Gila River terrace; elevation 496 m.
Topography: Level on tread; slope < 1 %.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), saguaro (*Cereus*), and cholla (*Opuntia*).
Sampled by: Gary Huckleberry, November 25, 1992.
Remarks: Soil pit excavated downslope from Hohokam stone alignment, approximately 50 m south of railroad. Railroad cut exposes 2 m of Gila River cobbles, gravels, and sands; cobbles and gravels have discontinuous calcium carbonate rinds on all sides (Stage II). Few pebbles and cobbles at surface and in soil. Soil colors are for dry conditions.

A 0-2 cm. Light brown to reddish yellow (7.5YR 6/5) sandy loam to loamy sand; weak, fine, subangular blocky; loose to soft (dry), not sticky and slightly plastic (wet); noneffervescent; gradual smooth boundary.

Bw 2-38 cm. Strong brown (7.5YR 4/6) sandy loam; weak, medium, angular blocky; slightly hard (dry), not sticky and slightly plastic; noneffervescent; abrupt smooth boundary.

Bkm 38-42+ cm. Pinkish white (7.5YR 8/2); massive; extremely hard (dry); violently effervescent; calcium carbonate plugs voids (Stage III+).

Geologic Surface: Ms2
Soil Profile: MGR-24
Classification: Paleargid
Location: Pinal County, Arizona; SE 1/4, NW 1/4, SW 1/4, NW 1/4, Sec. 9, T. 4 S., R. 11 E.
Physiographic Position: Gila River terrace; elevation 502 m.
Topography: Level on tread; slope < 1 %.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), saguaro (*Cereus*), and cholla (*Opuntia*).
Sampled by: Gary Huckleberry, November 25, 1992.
Remarks: Soil pit excavated approximately 40 m from western edge of terrace. Cryptocrystalline cobbles are common at surface; phaneritic cobbles at surface very pitted. There is a mixture of tributary rhyolitic gravels and Gila River gravels. Clay skins in Bt1 and Bt2 horizons are few and thin, but in Bt3 horizon they are many and thick. Alluvium from adjacent was is pale brown (10YR 6/3). Soil colors are for dry conditions.

Bw 0-10 cm. Reddish yellow (7.5YR 6/6) gravelly sandy clay loam; weak, fine, subangular blocky structure; slightly hard (dry), slightly sticky and slightly plastic (wet); noneffervescent; abrupt smooth boundary.

Bt1 10-25 cm. Reddish brown (5YR 4/4) cobbles and gravels in sandy clay matrix; single grain; loose (dry), not sticky and not plastic (wet); noneffervescent; clear smooth boundary.

Bt2 25-34 cm. Yellowish red (5YR 4/6) very gravelly sandy clay; weak, fine, angular blocky structure; hard (dry), very sticky and very plastic (wet); noneffervescent; abrupt smooth boundary.

Bt3 34-48 cm. Yellowish red (5YR 4/6) sandy clay; weak, fine, angular blocky structure; slightly hard (dry), very sticky and very plastic (wet); noneffervescent; abrupt smooth boundary.

Btk 48-65 cm. Yellowish red (5YR 4/6) sandy clay with few, very fine, prominent pinkish gray (5YR 7/2) mottles of calcium carbonate; weak, fine, angular blocky structure; hard (dry), very sticky and very plastic (wet); mottles strongly effervescent (Stage I); abrupt smooth boundary.

Bkm 65-67+ cm. Pinkish white (5YR 8/2); massive; extremely hard (dry); violently effervescent; calcium carbonate plugs voids (Stage III+).

Geologic Surface: Ms1
Soil Profile: MGR-25
Classification: Durorthid
Location: Pinal County, Arizona; NW 1/4, NW 1/4, SW 1/4, Sec. 10, T. 4 S., R. 11 E.
Physiographic Position: Gila River terrace; elevation 526 m.
Topography: Level on tread; slope < 1 %.
Vegetation: Creosote (*Larrea*), bursage (*Franseria*), and cholla (*Opuntia*).
Sampled by: Gary Huckleberry, November 25, 1992.
Remarks: Soil pit excavated approximately 30 m from southern edge of terrace. Fragments of Bkm horizon are common at surface. Gila River cobbles are clustered near the edges of the terrace. There are several stone piles and alignments (Hohokam agricultural features). Bw has a high silt content. 2Bkqm contains buff and cream-colored laminae of silica. Soil colors are for dry conditions.

Bw 0-23 cm. Light yellowish brown (10YR 6/4) sandy loam; weak, medium, subangular blocky structure; soft (dry), slightly sticky and slightly plastic (wet); strongly effervescent; calcium carbonate is disseminated; abrupt smooth boundary.

2Bkqm 23-35+ cm. Pinkish white (7.5YR 8/2); massive; extremely hard (dry); violently effervescent; calcium carbonate and silica plugs voids and is laminar at top (Stage IV+).